CHAPTER 7

A NETWORK IN SPACE

The roots of a satellite-based communications network can be traced to 1945, when a Royal Air Force radar specialist and member of the British Interplanetary Society, Arthur C. Clarke expounded on his concept of what is known today as the "geosynchronous satellite." The reason geosynchronous communication satellites are needed is really very simple: The curvature of our Earth limits how far we can see. Consequently, a network of tracking stations, even when spread around the world, can only see and communicate with an orbiting satellite about 15 percent of the time, only when it passed within the station's field-of-view. In his article, Clarke accurately hypothesized that a satellite placed into orbit at an altitude of 35,900 kilometers (22,300 miles) over the Equator would circle Earth at the same angular rate that Earth rotated. In such an orbit, it would appear to an observer on the ground to be hanging motionless over the Equator. Thus, he concluded that a stationary satellite at geosynchronous altitude would be in an excellent position to relay communications around the globe. To this end, he suggested that use of three *manned* satellites in orbit could be used to relay programs for the newly invented medium of television.[1]

Clarke's article apparently had little lasting effect, however, in spite of the story being repeated in the 1951–1952 publication *The Exploration of*

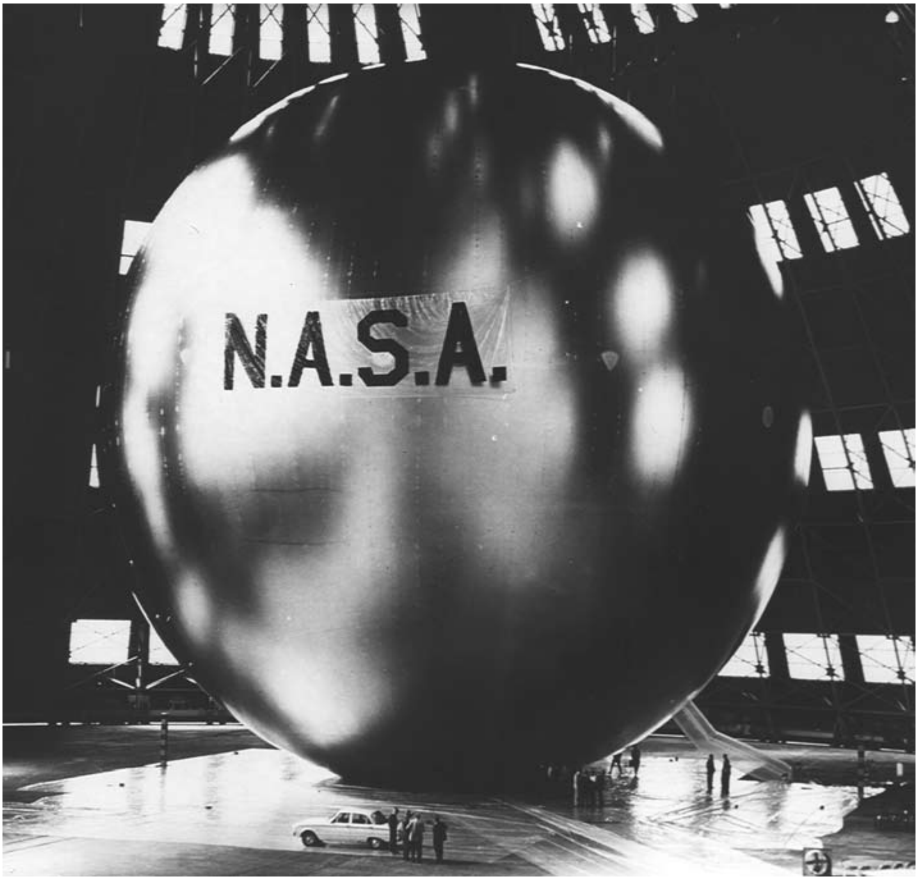
Space. Lying dormant for several years, it was not until 1954 when a scientist named John R. Pierce at AT&T's Bell Telephone Laboratories carefully reevaluated the various technical merits (and the potential commercial windfall) of Clarke's proposal. Since the terms geosynchronous and geostationary had not yet been invented, Pierce, in a 1954 speech and 1955 paper, elaborated on the utility of a communications "mirror" in space. Along these lines, he added the concept of a medium-orbit "repeater" and a 24-hour orbit "repeater." In comparing the communications capability of a satellite, which he roughly put at 1,000 simultaneous telephone calls, with the capacity of the first trans-Atlantic telephone cable (TAT-1), which could then carry only 36 simultaneous telephone calls at a cost of $40 million dollars—Pierce wondered if such a "repeater satellite" could be worth over a billion dollars to his company![2]

Within 10 years, Clarke's and Pierce's concept would be translated into reality as communication satellites enabled viewers from around the world to enjoy the 1964 Tokyo Olympics live on television.

Spurred on by the 1957 launch of Sputnik 1 and later the Explorer satellites, the use of artificial satellites for communications quickly became a high-interest item in academia, the fledgling space industry and in the government. Many in the military saw its obvious strategic potential. NASA too, understood its incredible potential towards global communications. However, due to Congressional fears of "duplication" and in keeping with NASA's civilian charter, the Agency pretty much confined itself to experiments with passive, reflective, mirror-like satellites such as Echo 1 and 2. These were essentially nothing more than gigantic, shiny, Mylar balloons that bounced radio signals from one point on Earth to another. Meanwhile, the DOD dabbled in the more "active" satellites which actually amplified the signals received, providing much higher quality and stronger returns.

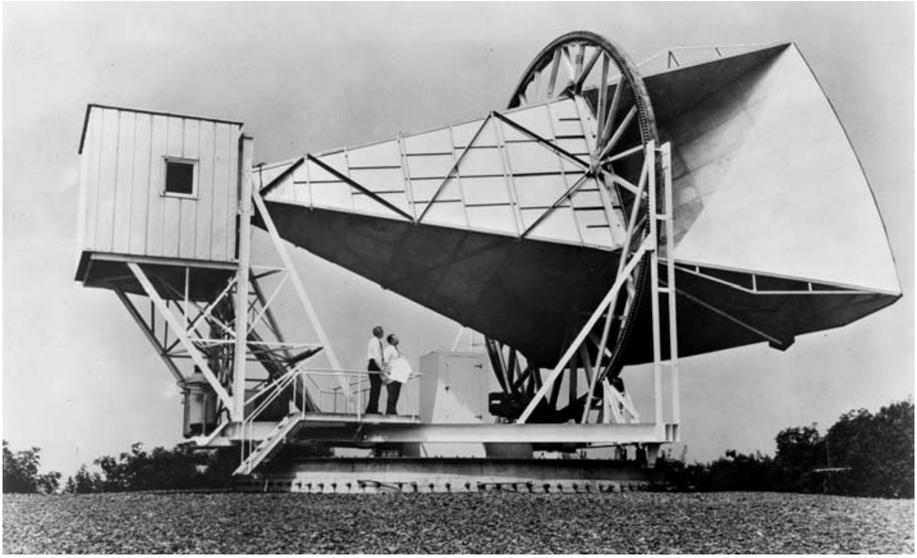
Government agencies, however, were not the only ones involved. In 1960, AT&T filed with the FCC for permission to launch an experimental communications satellite with the full intention of following it up with an operational system. The U.S. government was caught somewhat off guard since there was really no policy in place to regulate the decisions needed to implement the AT&T proposal. (This is somewhat akin to the situation that the FAA found itself in during the 1990s with respect to the commercial space launch market. Many laws and policies were in effect, but the FAA found itself having to quickly adapt them into guidelines for a cottage industry interested in this new commercial arena.)

The pace quickened. By the middle of 1961, NASA had awarded a competitive contract to RCA—who won the contract over AT&T and Hughes Aircraft—to build the medium-orbit (6,500 kilometer or 4,000 miles high), Relay communication satellite. Undeterred, AT&T would soon build its own satellite, the Telstar, which NASA launched for them on a cost-reimbursable basis in July 1962.



Echo, America's first communication satellite, was a passive spacecraft based on a balloon design created by engineers at NASA's Langley Research Center. Made of highly reflective Mylar, the satellite measured 30.5 meters (100 feet) in diameter. Once in orbit, residual air inside the balloon expanded, and it would begin its task of reflecting radio transmissions from one ground station to another. Satellites like Echo 1 shown here during an inflation test generated a lot of interest because they could be seen with the naked eye from the ground as they passed overhead. (NASA Image Number GPN-2002-000122)

On 25 May 1961, President John F. Kennedy spoke to the nation, committing to an American Moon landing by the end of the decade. But in another, long forgotten, portion of that speech, the President also committed the country to build a global satellite communications network. To this end, NASA and the Hughes Aircraft Company began developing a small, experimental, geostationary satellite called Syncom. Its first launch in January



Antennas for communicating with satellites have come a long way. "The Horn" antenna at Bell Telephone Laboratories in Holmdel, New Jersey was built in 1959 for pioneering work in communicating with the NASA Echo satellites. Made of aluminum with a steel base, it was 15 meters (50 feet) in length and weighed in at 18 metric tons (40,000 pounds). Used to detect radio waves that bounced off Echo, this primitive antenna was later modified to work with the Telstar Communication Satellite. In 1990, The Horn was dedicated to the National Park Service as a National Historic Landmark. (NASA Image Number GPN-2003-00013)

1963 went successfully, but unfortunately, the satellite failed to operate after injection into geostationary orbit. The second attempt in July 1963, though, was a complete success. These pioneering experiments soon paved the way for the semi-private, U.S. government subsidized Communications Satellite Corporation, COMSAT, that was formed as a result of the Communications Satellite Act of 1962 (a fallout from Kennedy's commitment), to pave the way for the world's first commercial communications satellite.[3]

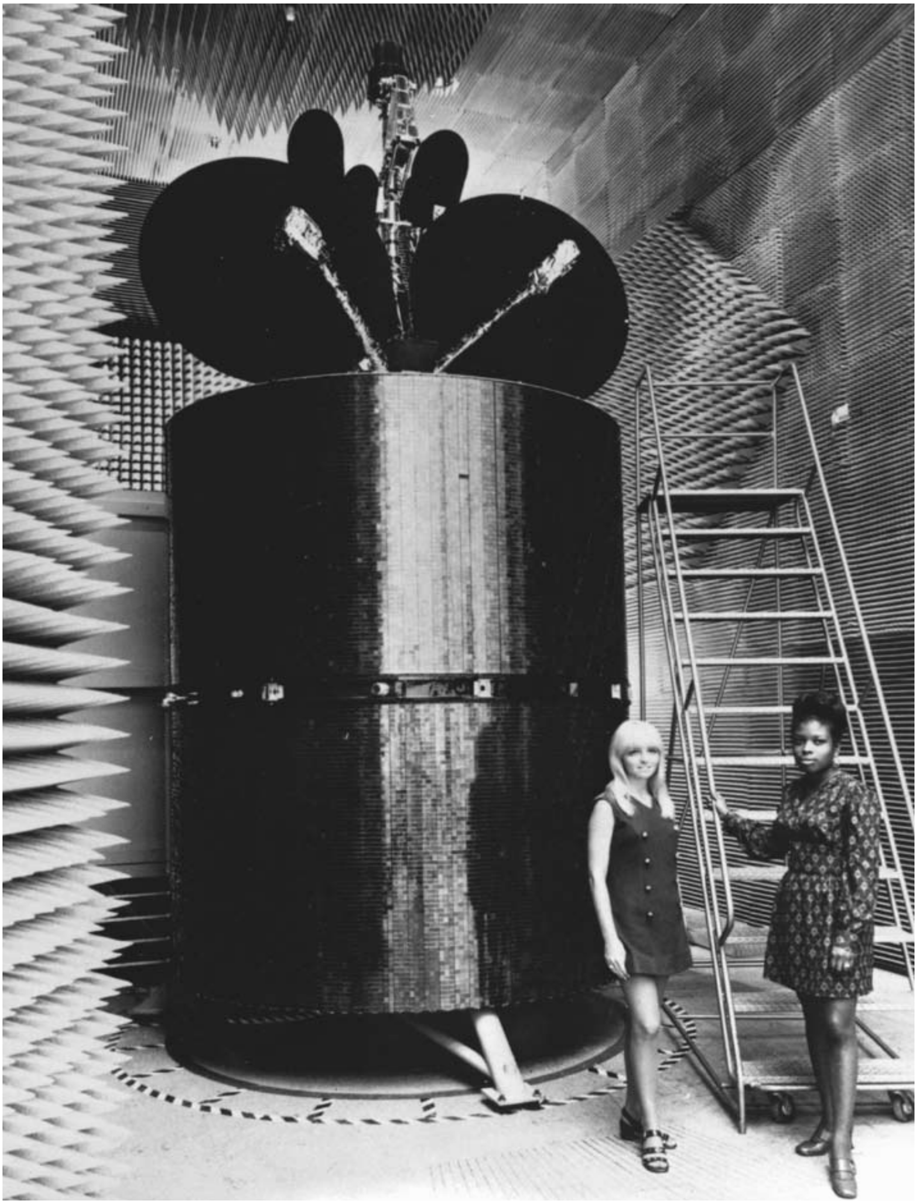
Not surprisingly, the United States was not the only country in the West interested in this new realm. Understanding full well the global nature of the endeavor, NASA began negotiations with the Europeans to build ground stations on their soil (negotiations which AT&T had begun two years earlier in preparation for its Telstar experiment). Soon, Earth stations existed in Great Britain, France, Germany, Italy, Brazil, and Japan. Further negotiations over the next two years eventually led to a new international organization, one which would ultimately assume ownership of the satellites and responsibility for management of the new commercial space communications network.

On 20 August 1964, INTELSAT (the International Telecommunications Satellite Consortium) was officially formed with America's COMSAT as a majority owner. INTELSAT would eventually come to have more than 140 member nations, becoming the world's largest commercial satellite communications service provider. In this cooperative, owners contribute in proportion to usage of satellite services and receive a return on their investment. On 6 April 1965, the consortium launched the Early Bird from Cape Canaveral, and the age of international satellite communications was born. Today, INTELSAT operates a fleet of more than 20 geostationary satellites, providing television, telephone, and data services to literally billions of people worldwide. To manage the system, the consortium establishes technical and operating standards for ground stations which all users must comply with. Using antennas as small as 1.5 feet in diameter, users such as television and telephone companies, along with data service providers around the world, can access the system on a 24/7 basis to support their customers.[4]

But back in the 1960s, much of the early use of the COMSAT/INTELSAT system was to provide circuits for NASA's communications network NASCOM, relaying data back and forth between ground stations and their respective control centers. By the end of the decade, fortuitous timing led to the INTELSAT-3 series completing the global network just days before a billion people watched on live television mankind's first steps on the Moon on 20 July 1969.

During this time, communication satellites were fairly simple and not very big. Like Syncom, they were all spin-stabilized. In order to keep proper orientation in the weightlessness of space, an object (any object) has to be stabilized, either actively with an attitude control system consisting of small thrusters, or passively by spinning so as to conserve angular momentum (like how a bicycle wheel or a top stays upright when spun). By the 1970s, three-axis stabilization using gyroscopes had matured to the point where they could be used to reliably maintain the orientation of a satellite in orbit.[5] This made a huge difference. Since a satellite would no longer have to be spinning, it could now accommodate large directional antennas to support high data rates and deploy very large solar arrays for power. With more power came more equipment, sophistication, and more capabilities.

Technology steadily improved through the 1960s and 1970s. Perhaps an even more important improvement than new stabilization techniques was the increase in the amount of power that RF signals can be transmitted at and the utilization of higher frequencies in the RF spectrum. At the heart of signal amplification is a device called the Traveling Wave Tube, or TWT. Invented by Austrian born physicist Rudolf Kompfner and his colleagues at



Started in 1964, the International Telecommunications Satellite or INTELSAT ushered in the era of communication satellites for everyday use. Today, the consortium consists of over 140 member nations. This photograph shows Intelsat IV in an anechoic (sound-absorbing) test chamber in 1972. Built by the Hughes Aircraft Company, NASA placed it in geosynchronous orbit over the Atlantic with a then state-of-the-art capacity of 6,000 voice circuits or 13 television channels. (NASA Image Number 72-H-872)

Bell Laboratories, the TWT amplifiers date back to the beginning of the space communications era. Early tubes had power output only in the one-watt range (less than a common household nightlight). By the early 1970s, though, TWTs with a couple hundred watt capabilities were becoming available. What this meant was that ground stations no longer needed large dish reflectors costing millions of dollars to build. Antennas for satellite services quickly and dramatically shrank to the point where a 3-meter (10-foot) dish costing around $30,000 could now do the job that once required a 26-meter (85-foot) dish.[6] Advancements have continued in this field to where today, direct-broadcast application satellites have TWTs in the 300 watt range, requiring receive antennas that are only a foot or two (0.3 to 0.6 meters) in diameter and which cost less than a hundred dollars a piece. This has resulted in a huge leap in the amount and types of services available to everyday users literally anywhere in the world—as evidenced by the boom in the number of satellite television subscribers in recent years.

These sweeping strides in communications satellite technology provided NASA with the technology it needed to turn the TDRSS (Tracking and Data Relay Satellite System) from a concept on the drawing board into reality.[7] In fact, it would not be an overstatement to call TDRSS a national resource, one that has totally transformed the way space communications are done. In its planning and conceptual stage for about 10 years, implementation of the TDRSS in the 1970s and 1980s was, without a doubt, the biggest evolution in NASA tracking and communications during that time. So different was TDRSS that, to put it simply, it made the sprawling network of global ground stations a thing of the past.

Of the many communication satellites launched prior to the Shuttle era, only one—ATS-6 on Apollo-Soyuz—played a key role for tracking and data acquisition on a human space mission. Its success in 1975 took place at an important juncture. By this time, the Agency had completed Apollo and had already conducted several years of feasibility studies on a space-based communications network. ATS-6 underscored the unique ability of a communication satellite to serve as an orbiting platform, greatly enlarging the field-of-view capable from a single location.

Thus, the timing seemed right to establish a completely new kind of network, one based in space. Cost-benefit analysis done by GSFC drove the point home. By the 1970s, the sheer number of American spacecraft requiring network support had exceeded 50 and the cost of running ground stations was rising. Moreover, the STDN, as a ground-based system, had inherent weaknesses. Each station, for example, could monitor only two spacecraft at the same time and all stations working together could only hold a spacecraft in view for a small percentage of each orbit. TDRSS changed all that. “The network will take on a whole different complexion, becoming primarily a satellite-to-satellite network. But the big advantage that we’ll get from that is the amount of coverage we'll get. That's the big benefit of TDRSS," said Henry Iuliano in comparing the expected performance of the TDRSS to the STDN.

> We have a very, very reliable network out there right now but it has wide gaps of information, compared to what we will get from TDRSS. There's no comparison. During the aborted Apollo 13 lunar mission, voice contact was very important because you would have to wait sometimes 20 to 25 minutes between contacts. We had to fit as much communication as possible into that short span, whereas now, once the TDRSS system is fully deployed, we'll have absolute coverage for a Shuttle mission. You can call and talk just about any time you want to.[8]

Its implementation greatly slashed the number of ground stations, saving NASA an estimated $500 million dollars in network operating expenses alone while providing this almost seamless communication capability.[9]

The original plan envisioned three satellites, each placed in geosynchronous orbit: one over the Eastern Hemisphere, one over the Western Hemisphere, and a spare positioned between the two. They would be connected to the ground at a single ground terminal. In this way, TDRSS could provide 100 percent viewing of spacecraft orbiting between 1,200 and 5,000 kilometers (745 and 3,100 miles) altitude. Craft orbiting above this altitude would be assigned to the DSN while for those orbiting below 1,200 kilometers, TDRSS could provide 85 percent coverage for—not perfect but still a far cry better than that offered by traditional ground stations.[10]

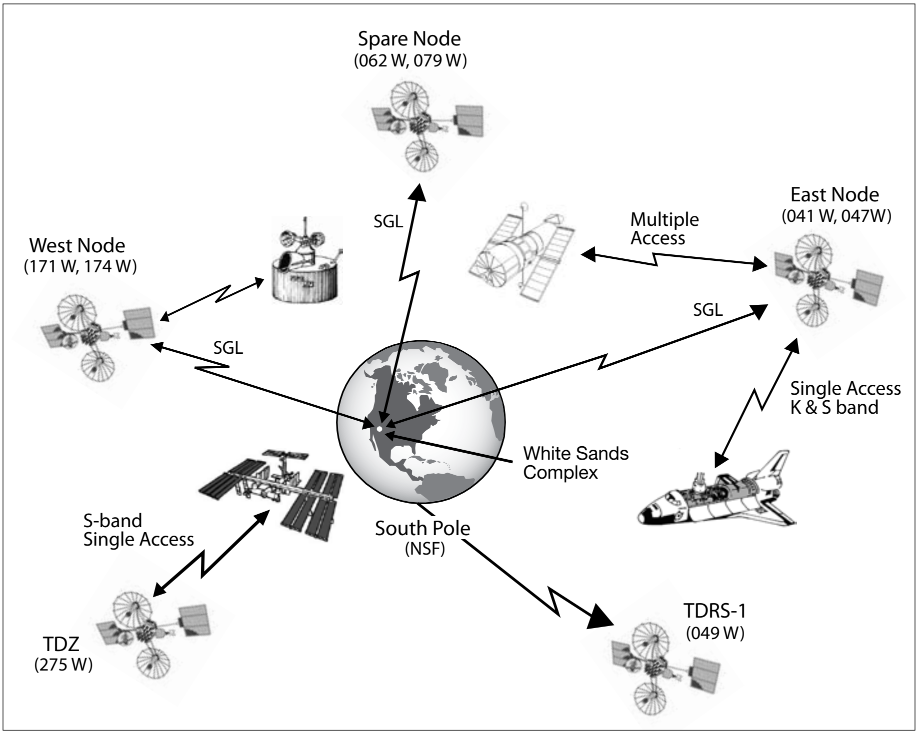
These hard facts were compelling and NASA's commitment to TDRSS was firm by the mid-1970s. Originally intended for inauguration with the Space Shuttle in the 1979 to 1980 time frame, implementation of the new system experienced many frustrations, and unfortunately, a tragic setback as well. This series of events was to prevent the TDRSS from meeting its full potential for nearly the entire decade of the 80s. Even though by the late 1970s, when the Agency knew that the new Space Network (SN) was not going to happen for a few more years, there was nevertheless optimism on the part of planners that there would not be too much of a delay between the inception of Shuttle flights and when NASA would have an operational SN in place. Even as late as December 1979, Goddard was counting on TDRSS taking over all tracking and data support of near Earth-orbiting spacecraft by 1982.[11]

Though it took the better part of the decade to complete, by 1989 NASA finally had what it had been waiting for. With TDRSS now available, the size of the ground network indeed shrank dramatically while communications coverage grew, from some 15 percent to over 85 percent, a six-fold increase. On top of that, network complexity was greatly reduced. TDRSS does not perform processing of user traffic but rather, operates simply as a

A drawing of the TDRS-3 spacecraft. The Tracking and Data Relay Satellite System (TDRSS) provides nearly uninterrupted communications with the International Space Station (ISS), the Space Shuttle and Earth orbiting satellites, replacing the intermittent coverage provided by the Spaceflight Tracking and Data Network (STDN) ground stations. (NASA Image Number MSFC-8893551)

"bent-pipe" repeater, one in which signals and data between spacecraft and ground terminals are relayed but not processed in real time. One Goddard network manager prognosticated (correctly, as it turns out) in 1989 on the future of space communications on the eve of a fully operational TDRSS network.

> We're certainly not going to go out of business. We'll start exchanging data through international programs, and there'll be increased contact with the universities and foreign space programs. We'll still maintain a NASCOM presence in Europe and Australia through the DSN and the domestic network is going to continue to grow in communications capabilities through the universities and scientific project control centers. As the tracking stations go away and the Shuttle flies on a regular basis, we'll have more and more satellites and more and more scientific data to exchange, so we'll be changing the network. Instead of linking up to tracking stations around the world, we're linking up users to the data we're getting back from the spacecraft, and that's going to continue to grow.[12]



The Tracking and Data Relay Satellite System, TDRSS. The first generation Space Network used S and Ku-band to relay communications from up to 20 satellites at the same time. Ka-band capability was added beginning with three second generation satellites in the early 2000s. (Adapted from Roger Flaherty, Satellite Communications, Goddard Space Flight Center, May 2002)

This is how the system works. Data, voice, and video acquired by the constellation of satellites are relayed to a centrally-located terminal on the grounds of NASA's White Sands Test Facility in southern New Mexico—the White Sands Ground Terminal—or on Guam. From there, the raw data is sent directly by domestic communications satellites to control centers at the JSC, the GSFC or wherever it may be needed by independent users. In this way, nearly continuous communications with the ISS, for example, is allowed. This permits far greater flexibility in mission operations than had been previously achievable with a network of stations on the ground. To carry out the commercial side of the program, TDRSS also serves the space and science community at large by providing near-continuous coverage for over two dozen low-Earth orbiting spacecraft all at the same time. As one former manager put it, this new kind of space-centric network "focuses on the total data system, from instrument to scientist."[13]

All this ties back to just how the TDRSS came about. Studies for a tracking and data system that would rely on satellites rather than on a network of ground stations date back to the early 1960s. It was the DOD, not NASA, who first planted the seed. In the interest of controlling the "high ground," the United States Air Force knew that a space-based communications network could be the key. To this end, they held discussions with the Lockheed Missiles and Space Company and General Electric to investigate the feasibility of putting into space a so-called network of "Instrumentation Satellites."

NASA, however, was not far behind. In 1964, tracking personnel at the GSFC requested that Headquarter's OTDA consider funding an "orbiting tracking and data station" as a research and development project. OTDA managers in Washington were intrigued with the idea and put it on the agenda for Future Advanced Studies. Two years later in April 1966, the RCA Astro-Electronics Division and Lockheed were both awarded six-month contracts to define the characteristics of what was by then called an "Orbiting Data Relay Network."

By fall of the following year, OTDA was convinced that the space-based concept had a future. Goddard was thus tasked to establish a Data Relay Satellite System (DRSS) Requirements and Interface Panel, which included specialists from human spaceflight and science applications offices from around NASA. This panel's assignment was to oversee the definition and startup of such a system.[14]

The DRSS focused on a basic plan that called for a two satellite network in geosynchronous orbit over the Equator. In this configuration, an "East" satellite would be placed off the northeast coast of Brazil and a "West" satellite placed southwest of the Hawaiian islands. The goal was to have a system that could "be developed to augment and, to the extent practical, replace certain of the facilities that [comprised] NASA's tracking and data acquisition network."[15] The Agency was hoping for an operational network in orbit in the 1974 to 1975 time frame. To do this, Goddard had to expend considerable effort designing a system that would meet user needs at a time when most of the users were not even around yet. In other words, how did NASA know that this system it was designing would meet the needs of a future user community for the next 15 years?

To answer these questions, network planners developed what was called "loading analysis" computer programs. These programs evaluated whether the designs would satisfy user demands and determined how changes to staffing and closure of ground stations would affect the existing users. Meetings were held to identify the needs, understand onboard recording capabilities, data dump requirements, antenna design, and orbit planning.

For instance, it was through such analysis that Goddard came to understand that two so-called Single Access (SA) antennas and an array of 30 Multiple Access (MA) antennas could be used to satisfy those needs. (The number of spacecraft that can be supported by the MA system is determined by the phasing equipment on the ground, not by the number of antennas on the spacecraft.) From a station closure standpoint, loading analysis was used to help phase-down ground station shifts and closures in anticipation of each successful TDRS launch.

By May of 1971, Goddard was ready to issue Requests for Proposals to the industry for design of what was now officially called the Tracking and Data Relay Satellite System—TDRSS. An open competition led to Hughes Aircraft and North American Rockwell both being awarded two-year design contracts. However, before the contractors could finish their studies, NASA management realized that a budget conscious Congress would likely not fully fund development from the ground up of an effort that was still at a minimum four or five years down the road.

NASA had to think about new ways to procure TDRSS.

In what could only be termed a radical departure from the way it had operated up until then—and in an effort to get the project started without committing the Agency to a future purchase of a suite of satellites—OTDA decided to *lease rather than buy* a satellite system. In other words, rather than proceeding with a government-owned and operated system, NASA would, in essence, negotiate with private industry for a long term contract, one that would have the latter sell communication services back to the government. Since TDRSS was categorized as a support program rather than an Agency research and development program, NASA considered leasing to be a viable option. Besides, all the technology required to implement the system was labeled as either off-the-shelf or in a high enough technology readiness level that leasing was considered no riskier than buying.[16]

In a flip-flop of the traditional customer-client relationship, the space agency was now a customer of private industry. Again, the impetus for this fundamental departure in the way NASA did business was rather simple and as usual, came down to economics. By obtaining this capability from industry on a long term, fixed price service basis, the Agency hoped to save money, and at the same time, spur on the commercial space sector.

In September 1973, Administrator James C. Fletcher wrote to individual members of Congress advising them of the Agency's budget needs for FY 1975. Among the new programs listed was TDRSS. Regarding the crucial role that the new system will play in Space Transportation System (STS) (Shuttle) operations, he wrote:

> Our studies have shown that the only way to meet our future tracking and data acquisition needs with reasonable expenditure of

> funds will be through a . . . TDRSS. Such a system will improve our Earth orbital tracking and data acquisition capabilities and meet the high data rates anticipated when the Space Shuttle is in operation, while at the same time, permitting the elimination of most of the ground stations in the present.[17]

Fletcher's statement to Congress captured *the main reason* for TDRSS: it was cheaper than augmenting the ground stations to meet Shuttle requirements.

The Agency had already identified six companies that were interested in the project, but, in this case, needed the assistance of Congress to develop the necessary legislation to authorize NASA to enter into such a contractual arrangement, since something like this had never been done before. Congress debated the wisdom of such a relationship through the spring of 1974, but finally authorized the go-ahead in May.[18]

Looking back over the last 50 years, the transfusion of technology from the government-borne space program to the private sector has occurred in many areas. Nowhere has this been more visible than in the realm of communications. Even in 1977, Gerald Truszynski summed it up rather succinctly when he testified before Congress, saying "The TDRSS contract, we think, is a good example of government developments moving into commercial applications."[19]

NASA now had the authority it needed to proceed with this leasing venture. It was at this time that the Agency's Headquarters made the (fatalistic in hindsight) decision that NASA had no basis to preclude telecommunications companies from bidding. The fallout of this decision was that by October 1974, no less than 27 companies or teams of companies had indicated their interest in bidding for the design, fabrication and operation of TDRSS. On 7 February 1975, Goddard issued a Request for Proposals for Phase I studies which would detail the system design and cost. In June, awards went to two contractor teams: RCA Global Communications, Inc., and Western Union Space Communications, Inc. A separate contract was awarded to Hughes Aircraft to define the user antennas systems that would be required by customer satellites.[20]

By 15 January 1976, Western Union and RCA had completed their six-month Phase I studies. Both were now intensely competing for the Phase II production contract, the winner of which would actually build and operate the system. These two were not the only ones busy. Throughout the year, announcements came of awards for several smaller, support contracts. One was given to Hughes, as expected, for the company to continue on the user (customer) antenna system. Others were awarded for building various support hardware. The big announcement for the TDRSS prime contract itself did not come, however, until the end of the year.

On 12 December 1976, in what could only be called a shock to the aerospace industry, NASA awarded the lucrative, 10 year, $800 million prime contract to Western Union Space Communications, Inc., otherwise known as Spacecom—a wholly owned subsidiary of the Western Union Corporation headquartered in Upper Saddle River, New Jersey. It ranked among the largest contracts ever awarded by the Agency, even dating back to the big procurement days of Apollo. Western Union, while a leading communication services provider (it continues to be one of the largest wire service companies in the world), had virtually no experience in the aerospace world.

Under the Western Union team, TRW's Defense and Space Systems Group in Redondo Beach, California would build the satellites and provide the computers and software for the ground terminal at White Sands. Unlike its prime, TRW *was* a leading satellite manufacturer for the DOD and NASA, and thus provided the valuable experience of working on large aerospace projects that Western Union so sorely lacked. In addition to TRW, the Harris Corporation's Government Communications Systems Division in Melbourne, Florida, was on the team. Harris, a leader in communications and information technology, was responsible for $60 million of the contract to build and integrate the system's antennas at the White Sands terminal.[21]

After the network was up and running, terms of the contract called for 10 years of services to be provided by Western Union Spacecom to NASA in both the space and ground segments. This included six spacecraft with components for a seventh. But here is where the contract was different. Unlike traditional procurements where the government provided funding from the onset, no money would be forthcoming to Western Union until the system was operational. Since no funds would be forthcoming from NASA until TDRSS became operational, the development of the project was financed with loans provided to Western Union by the Federal Financing Bank, an arm of the U.S. Treasury. To make this work, Congress had to actually pass a law, which they did on 30 July 1977. Under the terms of Public Law 95-76, NASA would make loan repayments to the bank once services began.[22]

Unfortunately, and almost from the beginning, the contract with Western Union ran into problems. While large, government procurements on this scale are already difficult enough to handle, the TDRSS procurement had an added level of complexity. More specifically, the space agency was trying (for the first time) to build what was known as a "shared system." What this meant was that TDRSS would actually serve two purposes: It would be designed and built to provide NASA with a new communications network, but it would also be designed and built to provide commercial communications. Part of this venture called for one satellite to be dedicated exclusively for use by Western Union to provide domestic communication services once the constellation was complete.

This sharing of the system introduced some technical complications into the system. But that was not the main problem. What really became an issue to NASA was that Western Union was unable to market the commercial part of it. Bob Spearing, NASA's Director of Space Communications who was at Goddard during this time, explained what happened:

> In a sense, they [Western Union] were ahead of their time. They were designing a commercial satellite package that worked at Ku-band. Ku-band was not a household word at the time. It was a new emerging capability and they just weren't able to get traction. So that created some difficulties in terms of how they were going to proceed with NASA. The idea of the shared system was that it costs less because the satellite would serve two purposes. When that started to go down the drain, there were a lot of contractual issues that transpired with NASA to try and resolve that problem leading eventually to NASA actually buying out the commercial side of the system.

By buying out the system, the Agency in essence changed TDRSS from a shared system back to one that was basically dedicated for NASA use. However, the commercial capability remained on the satellites. As Spearing said, "The design was far enough along at that point that it would have been much more costly to scrap the design and start over, so we actually built the satellites with the commercial capability."[23]

In 1980, in the first of a succession of moves, the TDRSS operations contract was transferred to a partnership of Western Union, Fairchild and Continental Telephone. Then three years later, in July 1983, Western Union got out of the contract all together by selling its 50 percent of the business to the other two partners. The buyout continued. In 1985, Fairchild, sold its share, leaving Continental Telecom—better known as Contel—as the sole owner of Spacecom and the TDRSS contract. This continued until 1990 when a new contract was negotiated which finally transferred ownership of the system back to NASA. Contel remained onboard but was now the space agency's contractor that operated the system for NASA.[24]

The failure of Western Union in their role as the TDRSS prime contractor can be traced in large part to the nature of the company itself. Unlike its subcontractors, TRW and Harris, Western Union was not a major player in the aerospace industry. As such, it operated in the highly regulated environment of the telecommunications industry where it was not unusual to find four lawyers and managers for every engineer. As a communication services provider, it knew how to get the most out of a network. However, it lacked the experience to actually build one. From a technical standpoint, the concurrent development of the TDRSS with the Space Shuttle in the late

1970s also meant that Western Union had to work closely with Rockwell (the Orbiter prime contractor) as well as the JSC. This was again something that the company did not do successfully. Western Union's function on the contract thus became more and more administrative than technical, even to the point where TRW ended up assuming most of the systems engineering and integration role.

Former Associate Administrator for the Office of Space Operations Robert O. Aller presented to senior Agency management and Congress in 1989 a "lessons learned" workshop from the TDRSS procurement process. Aller gathered 30 NASA and industry people who were closely involved in the process to review its successes and its problems. The eight lessons learned concisely addressed the heart of the matter:

1 *Shared Service Concept.* The concept of combining a commercial need with an established NASA need is valid, and may offer significant savings to the government through shared costs; however, the rights and operational utilization needs, availability, and privileges of each party must be clearly established in advance.

2 *Leased-Service Concept.* A leased-service concept should be based on the use of available commercial services or existing system technology if service is mission-critical.

3 *Interdependency with Government-Provided Services.* The interdependency of government-provided services to the establishment of a shared-lease service should be avoided or minimized to avoid government impact to the enabling of the leased services.

4 *Fixed-Price Contract for Developmental Work.* A fixed-price contract is not appropriate for development of a mission-critical support system where significant technology development may be required or where substantial changes to requirements may occur.

5 *Government Control Under Leased Service.* Under a leased-service arrangement, NASA must accept some loss of control over physical assets and accept risks of system outages or failures.

6 *Operational Interface.* In a fixed-price environment, establish the government/contractor operational interface at a point where changes in requirements affect only the government side, so far as possible.

7 *End-to-End Engineering and Operations Analysis.* In a leased-service approach to obtaining a mission support capability, it is just as essential initially to establish a comprehensive end-to-end systems engineering analysis and an operations and testing plan as would be done in a conventional NASA space system development program.

8 *Considerations for Prime Contractor.* The prime contractor must be one who has an extensive background in the business at hand.[25]

Spearing elaborated on these lessons and what happened:

> In a sense, it was like NASA does today. In other words, if NASA lets a contract today, we would be in that oversight and management role and we would have a group of contractors handling the various elements, usually one lead contractor with some subcontractors associated with it. So we had this extra layer in there, if you will, with Western Union, driven principally by this shared system concept.[26]

Despite these challenges, work on TDRSS pressed on. Entering its final year of development in 1979, hardware fabrication continued in both the space and ground segments.[27] In the space segment, manufacturing of the high precision spacecraft antennas was the main item. Other activities included finishing up work on the propulsion system, specifically, qualification testing of the propellant tanks and acceptance testing of the Reaction Control System (RCS) that will be used to maneuver the satellites. In the ground segment, the Operations Building and ground antenna installation at the White Sands Ground Terminal (WSGT) were completed while hardware checkout and software development continued.[28]

Since nothing like TDRSS had been built before, technical challenges were expected. They were essentially the kind of things expected with building a brand new system, both in the design, and in particular, with the software. One way to describe the nature of a networked system involving many components such as the TDRSS is that it is "tightly coupled." This means that the software is such that if there is an anomaly in one part, it is going to affect a lot of other parts of the system. Along these lines, TDRSS was not only a tightly coupled system but an integrated system as well, with many subsystems that all had to work together. As a forerunner to today's so-called lights-out operation, TDRSS was envisioned by its designers to be capable of around-the-clock, unattended automatic operations.

For example, an operating schedule could be uploaded to a TDRS spacecraft. From there, it was up to the software to control the system, both on the ground and aboard the spacecraft—to configure links and acquire a given user satellite at the appropriate times. This was not at all trivial considering that each TDRS might be accessing 20 satellites at the same time, each in their own orbit while entering and exiting the spacecraft's field-of-view. With scheduling now automated, the number of ground controllers and the operational cost could be greatly reduced, to the point where personnel were needed only to monitor the system and implement changes. This move to systems automation was a major intent of the TDRSS. Thus for TDRSS to work, the software simply had to work.

Eventually, TRW engineers, working with Goddard, ironed out the problems. To demonstrate its capability, Spearing recalled that

> One day, just to show off a little bit, when we got it working, we had the operations team actually get up from their consoles and walk out of the room. We actually watched from a monitor to see how the system did. It went right through the whole process, acquired the spacecraft, got the signal and the data flowed out the back door. We wouldn't do that normally—just sort of a little showoff thing that we did for the local folks. We were not tracking the satellite operationally, just using it as a target of opportunity.[29]

But it proved the point: TDRSS was ready.

Another key hurdle that had to be cleared by the Agency as the initial operating capability of TDRSS approached was to make sure that there was not going to be radio frequency interference with other transmissions. A FCC Electromagnetic Compatibility Analysis was done in Annapolis to make sure that NASA's new system would "operate on a not-to-interfere basis with other services" operating in the 13.25 to 15.35-GHz regime.[30] At the heart of this analysis were classified DOD assets that operated in the same frequency range.

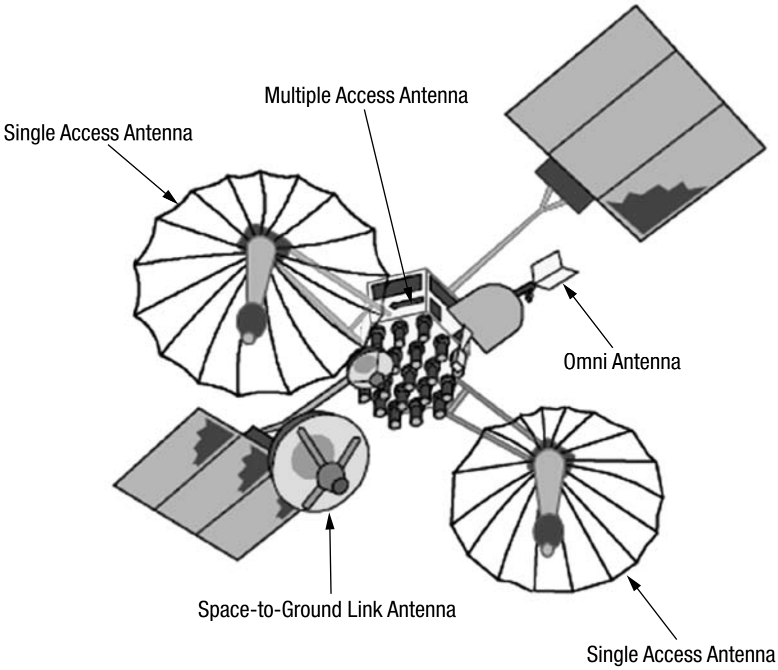
With the FCC analysis showing no serious radio frequency conflicts—and with the planned initial operating capability of the Space Shuttle quickly approaching—GSFC, that same year, made some rather significant decisions. The most important of these had to do with how the new satellites were going to be launched. Instead of sticking with the original decision to use a combination of expendable launch vehicles like the Atlas/Centaur and the reusable Shuttle, it tied TDRS launches exclusively to the latter. To do this, the spacecraft would be mounted atop an Inertial Upper Stage (IUS) rocket and the whole stack loaded horizontally inside the Shuttle payload bay. Once in Earth orbit, the TDRS/IUS stack would be raised up and gently deployed (literally pushed away) from the Orbiter. After it had moved a safe distance, the IUS would be ignited placing the TDRS on a course to geosynchronous orbit. The launch mode was officially tied to cost but ostensibly made the Shuttle that much more indispensable as it would now be the TDRS's only ticket into space. NASA, in essence, became a key supplier to its own satellite contractor. It was a watershed decision, one that would end up directly affecting the fate of TDRSS for years to come.

Other modifications had more to do with the capabilities of the satellite itself. Provisions for increasing spacecraft weight, reliability and station-keeping fuel reserves were added. Its tolerance in high radio frequency interference environments up in geosynchronous orbit was improved. (A Spacecom analysis done the year before had indicated that pulsed interference signals emanating from ground radar systems could create substantial TDRSS system upsets.) Overall, the value of these modifications added about $80 million to the project, which brought the total value to $866 million, plus award fees. When it became apparent that the Shuttle was not going to fly until after 1980, NASA slipped the schedule and delayed the launch of TDRS-1 until December 1980. As it turned out, it would not fly until 1983.[31]

From 1983 to 1995, NASA launched seven (TDRS-1 through 7) first generation TDRSS satellites. At the time, they were the largest and most advanced communication satellites ever made, weighing 2,270 kilograms (5,000 pounds) each and measuring 17.4 meters (57 feet) from one end of the solar panels to the other (equivalent to the height of a five-story building). In fact, the spacecraft was so large it would collapse under its own weight and could only be opened in the weightlessness of space.[32] Physical attributes aside, the heart of the spacecraft is its data handling capability. Operating in the S- and Ku-band, each satellite's electronic relay system could handle up to 300 million bits of information per second (300 Mbps), unheard of at the time considering 150 Mbps was considered high-rate service. Since eight bits of data make one digital word, this capability was somewhat akin to processing three and a half, 20-volume sets of encyclopedias every second.[33]

Looking somewhat like a giant, robotic bird out of a science fiction novel, the TDRSS spacecraft had several distinguishing, easily recognizable features. Foremost among them were the two huge, wing-like solar arrays which provided the satellite with over 1,800-watts of electrical power. The total array consisted of six (three on each side) 3.8 by 1.3-meter (12.6 by 4.2-foot) panels weighing approximately 130 kilograms (288 pounds) with a total photo-cell area of 30 square meters (317 square feet). These wings were movable so they could be kept pointed to the Sun. To do this, the arrays rotated about a common axis by two identical electro-mechanical drive assemblies which were individually controlled (Sun oriented) by the onboard Attitude Control System (ACS).[34]

Solar energy converted by the photo-voltaic cells was then used to charge the onboard nickel-cadmium (NiCd) batteries. These were capable of producing a power output of 1,440 watts and were housed in the hexagonal



Single Access Antenna

- Dual-frequency communications:
  - S-band: 2.025–2.120 GHz (Forward), 2.200–2.300 GHz (Return)
  - Ku-band: 13.775 GHz (Forward), 15.0034 GHz (Return)
- Circular polarization (LHC or RHC)
- ±22ºE-W, ±28ºN-S rectangular Field-of-View

Multiple Access Antenna

- 30 Elements: 12 diplexed for transmit/ 30 for receive
- S-band communications:
  - 2.1064 GHz (Forward)
  - 2.2875 GHz (Return)
- Circular polarization (LHC only)
- ±13º conical Field-of-view

Omni Antenna

- S-band TT&C
- LHC polarization

Space-to-Ground Link Antenna

- 2.0m Ku-band antenna:
  - 14.6–15.25 GHz (uplink)
  - 13.4–14.05 GHz (downlink)
- WSC/GRGT-TDRS uplink/ downlink
- Orthogonal, linear polarization

The first generation Tracking and Data Relay Satellite (TDRS-1 through 7). (Adapted from Space Network User's Guide, SNUG-450, Revision 8, NASA Goddard Space Flight Center) equipment module of the main body of the spacecraft. Since electricity was a precious commodity (true of any spacecraft), TDRS battery usage was carefully monitored and controlled via the ground at White Sands. To maintain spacecraft weight symmetry, these batteries were configured in two assemblies, each comprised of 36 sealed NiCd cells. With each assembly weighing 66 kilograms (145 pounds), they were quite heavy, but had good electrical capacity at 40 amp-hours each, about that of an automobile battery.[35]

To show just how far technology had come over the years, the 10 milliwatt mercury battery that powered the transmitter on the old Vanguard satellite was designed to last 10 to 14 days. Since the TDRS batteries were not self-contained but rechargeable via solar power, their design life was 10 years minimum. Since the spacecraft had four major power busses, electricity was routed from the solar arrays and batteries to the spacecraft systems using an onboard Power Control Unit (PCU). As its name implied, the PCU controlled the charge and discharge rates of the batteries.

All active space vehicles require some type of ACS, or Attitude Control System—unless the spacecraft is purely passive like the Echo. On the TDRS, the onboard ACS contained all the equipment necessary to control its orientation and stabilization. In addition, it served to point the antennas, drove the solar arrays and controlled thruster firings for precise, three-axis station keeping. Like most modern control systems, the ACS used a combination of miniature momentum wheels, gyroscopes, and accelerometers to precisely measure its inertial attitude and position in space (exactly how it was oriented with respect to the stars and the horizon). An important capability that the ACS provided was to recover the satellite should there be a loss in attitude control—for example, a spin from a highly unlikely, nondestructive impact with space debris.[36]

Since the spacecraft was designed to stay in orbit for at least 10 years, it carried its own fuel to provided impulses for maneuvering and precision station keeping. Onboard were 680 kilograms (1,500 pounds) of hydrazine propellant, enough to operate the spacecraft for 10 years.[37] Like electrical power, the propellant budget was also carefully monitored on the ground. Rounding out the ACS was a solar sail which compensated for the effects of solar wind against the asymmetrical body shape of the satellite.

In addition to power and propulsion, a critical requirement for any spacecraft is the thermal protection needed for it to survive the extreme temperatures of space. On the surface of Earth, we are protected by the atmosphere so that temperature changes are relatively gradual. But outside the atmosphere, temperatures can swing by more than 280°C (500°F) during each orbit. When TDRS was in daylight, the temperature could reach 117°C (243°F); when it was on the night side, the temperature dropped to -173°C (-279°F). This is why spacecraft are often seen wrapped in gold thermal protection blankets. TDRS's Thermal Control System (TCS) maintained its temperature within acceptable limits during all prelaunch, launch, orbit insertion, and on-orbit activities for the duration of its mission. To control the temperature, the TCS used a combination of insulation blankets, radiator panels, thermostatically controlled heaters, and special reflective surface coatings. For example, radiators were located on the upper and lower faces of the equipment compartment to help reduce solar heating effects. Components with nonradiating external surfaces were covered by aluminized Mylar or Kapton insulation blankets which were electrically grounded together to the main spacecraft structure so as to prevent any on-orbit static charge build up.[38]

Along with the solar arrays, the antennas of the spacecraft were undoubtedly its most prominent features. In fact, TDRS carried five antennas. Particularly noticeable were the two 4.9-meter (16-foot) diameter, high-gain parabolic antennas which resemble giant parasols after unfurling. These were the so-called Single Access (SA) antennas, providing dual frequency communications at both the S-band (2.025 to 2.300 GHz) and Ku-band (13.775 to 15.0034 GHz). They were called SA because they tracked and relayed communications only with a single user spacecraft at any one time, in response to ground commands. The two SA antennas were steerable in two-axes and could be slewed for this purpose, following an object as it moved below, crossing TDRS's field-of-view.[39]

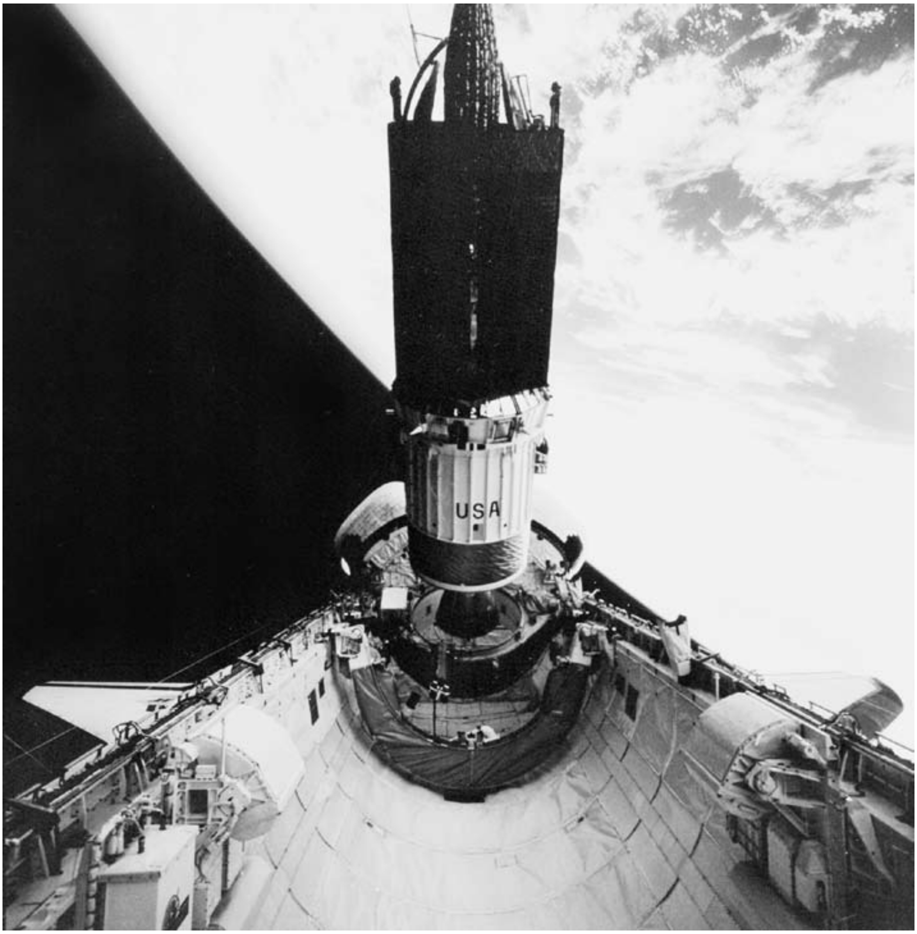
The high-rate service provided by these antennas was available to different satellite users who wanted to use the TDRSS on a time-shared basis. While the antenna may only be pointed at a single position, it was capable of supporting two users if they were operating at the different S- and Ku-Band frequencies. In other words, with the SA antennas capable of handling dual frequencies, each could actually be used to support two user satellites at the same time—one on S-band and one on Ku-band—if both were within the antenna's field-of-view. To keep design complexity at a minimum and to reduce circuit cable loss (that is, loss of radio signal strength as it travels through a finite length of wiring), the SA receivers and transmitters were actually mounted on the back of these large antennas.

Since every pound that is launched into space drives up the cost, materials are usually selected with as high a strength-to-weight ratio as possible, and as durable as possible; exotic manufacturing techniques are thus not uncommon. This was particularly true with something as big as the SA antennas. In this case, the primary reflector surface was made of a molybdenum wire mesh, woven like cloth, on the same type of machine used to make material for women's hosiery. For RF reflectivity and thermal tolerance, it was clad in 14-carat gold. When unfurled, its 18.9 square meters (203 square feet) of mesh was stretched tightly on 16 high-strength tubular ribs by fine, thread-like quartz cords. In this way, the antenna looked somewhat like a large, glittering, metallic spiderweb. Despite the size, the entire antenna structure weighed only about 23 kilograms (50 pounds) on Earth. To help explain their lightweight sophistication, NASA liked to publicize the following fact: Because of the support and structure that would be needed to counterbalance the effect of gravity, an antenna of similar capability and size based on Earth would need to weigh about 2,270 kilograms (5,000 pounds).[40]

Mounted on the lower side of the spacecraft's main body was the MA antenna. It was an electronically steerable, 30-element, phased-array antenna used to relay communications for multiple customer satellites simultaneously. To relay signals, 12 of the elements—called helices—were diplexed (split) for transmit and receive while all 20 were used as receive elements. Signals from each helix antenna were received at the same frequency, multiplexed or combined into a single composite signal and transmitted to the ground. In the ground equipment, the combined signal was demultiplexed and distributed to 20 sets of beam-forming equipment that discriminate among the 30 signals to extract signals of individual users. So a TDRS functioned somewhat like a celestial switchboard, receiving data from up to 20 different satellites while transmitting to 12, all at the same time. (The 12 that it was transmitting to could be other satellites or be the same ones from which it was receiving data.)[41]

From its vantage point at geosynchronous altitude, the 13° field-of-view of the MA meant it could see all spacecraft in orbits of 1000 km (620 miles) or below—the majority of low-Earth orbit spacecraft. Not only could it track all spacecraft below this altitude, it could also track many aircraft simultaneously. The MA service was attractive because it was very reliable, and for TT&C and low science data rate functions, it could provide user support everywhere and at any time. By contrast, the SA service was attractive because it could handle high data rates (300 kbps for S-band or 25 Mbps for Ku-band SA forward service versus only 10 kbps for MA service). Another difference was that the MA antenna operated only in the S-band. More specifically, it forwarded signals at 2106.4 MHz and received return signals at 2287.5 MHz.[42] When the system was being designed in the 1970s, this S-band only capability was deemed sufficient by most communications experts for handling the commercial satellite traffic then envisioned for the coming decade. This is only partially true now 35 years later.

While the Single and Multiple Access antennas were fine for communicating, tracking, and relaying data between the TDRS and other satellites, they could not be used to actually link the spacecraft with the ground. This was done with a separate Space-to-Ground Link antenna, or the SGL. It was a pointable, 2-meter (6.6-foot) diameter dish whose only purpose was to provide the uplink and downlink between the TDRS and the ground terminals at Whites Sands and Guam. Signals were relayed with the SGL using the more bandwidth efficient Ku-band (13.4 to 15.25 GHz). The SGL antenna, unassuming in appearance compared to the pair of SA antennas, handled all



The Tracking and Data Relay Satellite (TDRS) stowed in the Shuttle payload bay is raised to a vertical attitude in preparation for deployment from low-Earth orbit. Shown here is TDRS-6 being deployed from the Shuttle *Endeavour* on STS-54 on 13 January 1993. Clearly visible is one of the Single Access (SA) parasol antennas seen folded at the top. The solar arrays are also in the stowed position. The Inertial Upper Stage (IUS) is visible below the satellite. (NASA Image Number STS054-71-025)

customer scheduling and service requests as well as NASA's own TDRSS command and telemetry. It was, in essence, the customers' only electronic link back to Earth.

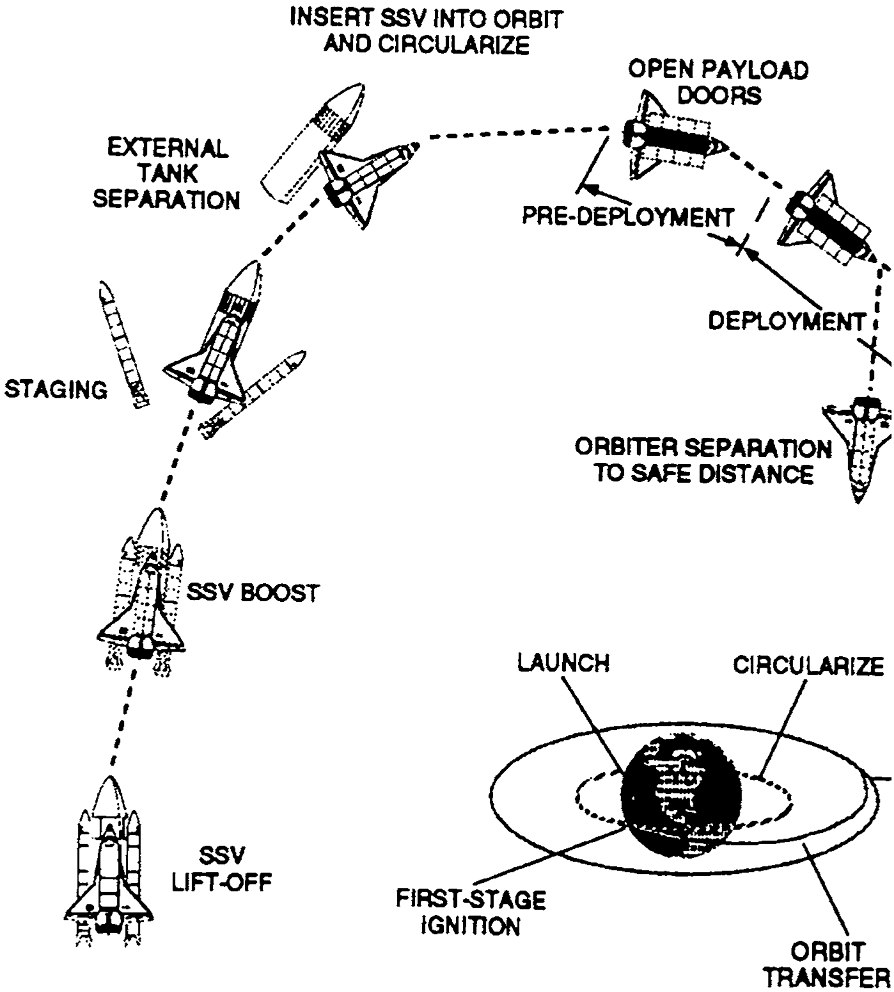
Finally, there was the Omni Antenna which supported the spacecraft's TT&C system. The TT&C collected data from the various onboard subsystems and transmitted the telemetry down to White Sands so that the spacecraft's health and status could be ascertained (for example, how fast were the batteries discharging). Conversely, it processed and implemented commands uplinked from the ground (for example, initiate thruster firings to rotate the craft). The TT&C system provided range and range rate information by computing precise turnaround-and-retransmission delays in signals to-and-from the ground.

Once the TDRS was operational in orbit, TT&C was normally done at Ku-band through the SGL antenna. However, there were exceptions and that was where the Omni came in. Looking rather inconspicuous—an oddly-shaped polygon—this omni-directional antenna mounted on the side of the main structural body operated in the S-band and was used strictly by NASA for command and control. Specifically, it was used during deployment from the Shuttle and, if necessary, during system recovery in the event of an emergency. It supported no customer services. With the Omni, TDRSS control on the ground could switch satellite operations to failsafe mode at any time for a variety of reasons: prevention of command lockout caused by failure of the primary SGL equipment, anomalous spacecraft attitude or pointing errors, and something that NASA hoped never happens—remote (hostile) takeover of the spacecraft. To put it simply, if one thinks of the SGL as the spacecraft's normal link back to Earth, then the Omni was, for all intents and purposes, the spacecraft's last-chance lifeline.[43]

★ ★ ★

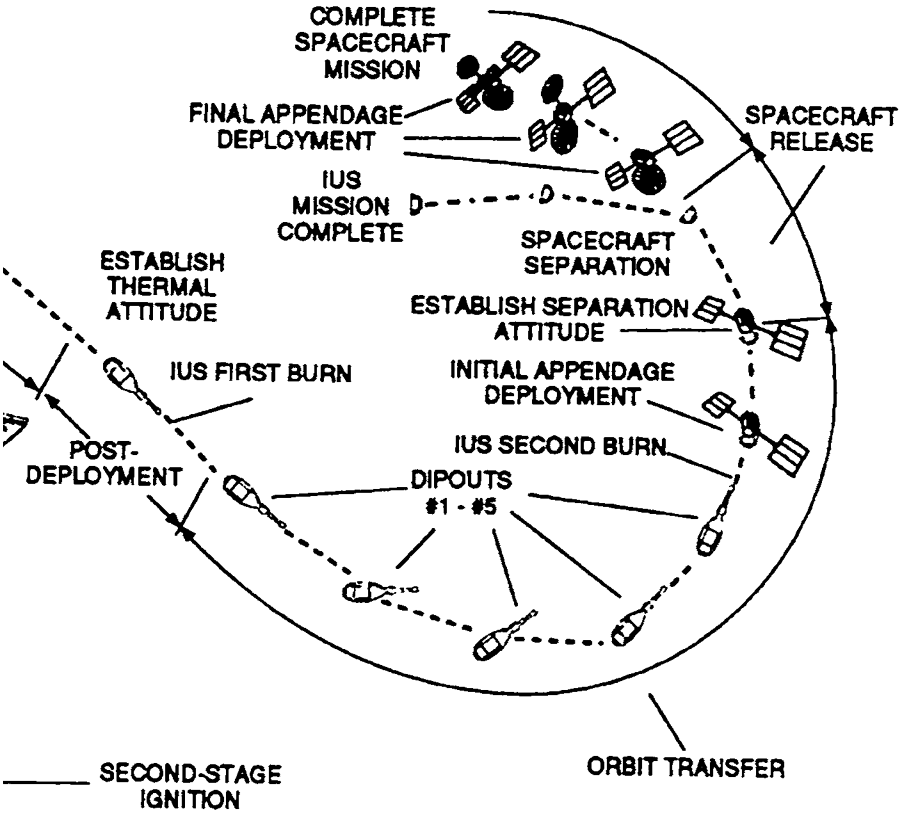
When STS-6 left Pad 39A at the KSC on the afternoon of 4 April 1983, it had a few firsts. It was the first flight of the new Shuttle *Challenger.* It was the first use of the improved, lightweight External Tank and the lightweight SRB casings. The mission had the first spacewalk (EVA) of the Shuttle program, one that lasted 4 hours and 17 minutes to check out the new generation of spacesuits that will be used by Shuttle astronauts. And finally, it launched the first Tracking and Data Relay Satellite, TDRS-1.

The launch, originally slated for 20 January 1983, was delayed several times due to leaks discovered in *Challenger*'s main engine fuel lines while it was on the pad. But in an unfortunate turn of events, as engine repairs were being made, a severe rain storm swept through the Cape that caused TDRS-1 to be contaminated while it was still in the Payload Changeout Room (PCR) at the pad. As a result, workers had to take it back to its checkout facility, have it cleaned, rechecked and remounted into the Shuttle payload bay. (The PCR and the payload bay first had to be cleaned out also.) With this temporary roadblock cleared, STS-6, commanded by Skylab veteran Paul Weitz, lifted off without further delay at 1:30 pm. EST on 4 April, sending the crew of four on their five-day mission to deploy the first TDRS.[44]



TDRS deployment sequence. (Space Shuttle Mission STS-54 Press Kit, January 1993, NASA Headquarters)

Deployment of a TDRS from the Space Shuttle is a well orchestrated series of events. After reaching orbit, the Shuttle’s payload bay doors are opened and its Ku-band antenna deployed. This antenna—stowed on the right, forward side of the payload bay—was crucial for checking out and communicating with the new satellite. As efficient a bandwidth as Ku-band is, one drawback of having to operate in this high frequency is the inherently narrow



pencil-like beam needed to focus the signals.[45] This makes it somewhat difficult for the SGL antenna to lock onto the signal in order to communicate with the Shuttle. However, since an S-band system can get by with an inherently larger beam, the Omni antenna is first used to lock the Ku-band antenna into position after the satellite is deployed from the Shuttle—a process known as acquisition. For anyone who has ever looked for an object in the night sky using a telescope, this is not unlike having to first use a finder-scope to point the main telescope in the vicinity of the star.

Once the Omni has locked on, the Ku-band system is turned on. To perform the acquisition, the Shuttle's Ku-band antenna is gimbaled so it can acquire the TDRS by executing a preprogrammed search. In this search, if the satellite's SGL signal is not detected within the first 8° of a scan, the search automatically expands to 20° and is repeated. The entire search typically takes only about three minutes. The scanning stops once the acquired signal strength meets a given threshold. At that point, the Ku-band system becomes operational.[46]

About an hour after release, having moved sufficiently far from the Shuttle, the IUS first-stage rocket motor is ignited. Built by Boeing Aerospace for the U.S. Air Force, the two-stage IUS solid-rocket boosts the TDRS into its 35,900 kilometer (22,300 mile) geosynchronous orbit since the Shuttle itself cannot go that high. This is then followed by a second-stage motor burn. Once this burn is successfully completed, the TDRS—still attached to the IUS—is well on its way to geosynchronous orbit and the Shuttle and her crew have essentially done their job.

There is, however, still more to do, this time by the ground. First, there is the geosynchronous insertion burn to circularize the spacecraft's orbit at geosynchronous altitude. This is followed by separation of the satellite from the now spent IUS. At this point, the TDRSS team at White Sands commands deployment of the solar arrays. The two 4.9-meter (16-foot) diameter SA antennas are then unfurled and pointed toward Earth for the spacecraft to begin its checkout. This testing will take place over the next three to five months. During this time, the ground will also command small thruster firings to slowly move the craft and position it at its desired operating location.

Joining Weitz on this mission were Pilot Karol J. Bobko and Mission Specialists Donald H. Peterson and F. Story Musgrave, both of whom would deploy the satellite from controls inside the aft flight deck. After *Challenger* was successfully inserted into a 286-kilometer (178-mile) circular orbit, the payload bay doors were opened and the TDRS-1/IUS stack was raised. Ten hours after launch Peterson flipped the switches which allowed the giant satellite to be released and gently pushed away from the Shuttle. The first engine burn went perfectly. However, the second did not; the motor shutdown prematurely.

For almost three hours, America's first TDRS appeared to be lost, deaf to all commands. At 9 a.m. EST the following morning—as Goddard engineers were busy with contingency procedures—the Goldstone tracking station received a faint indication that it had indeed separated from the spent IUS. However, its orbit was far from what was needed. Instead of a nice, circular 35,900 kilometer orbit, the incomplete engine burn had stranded TDRS-1 in a useless 35,325 by 21,790-kilometer (21,950 by 13,540- mile), elliptical orbit. Furthermore, instead of zero inclination (orbit parallel to the

Equator), it was crossing the Equator at an angle of 2.4º. As if that was not enough, the spacecraft was spinning out of control at an alarming rate of 30 revolutions per minute, or once every two seconds.

From the ground, the situation looked bleak. There was hope, however: Use the onboard ACS (designed only for station keeping maneuvers and for adjusting the satellite's location) to actually finish boosting it into geosynchronous orbit. Over the next two months, engineers at Goddard, TRW and Contel worked out a series of burns using the small (one pound thrust) ACS thrusters to carefully nudge the spacecraft into the proper orbit. Since the thrusters are so small, this orbit transfer could not be done with one maneuver. It, in fact, took 39 separate commands and consumed some 400 kilograms (900 pounds) of the usable 635 kilograms (1,400 pounds) of fuel onboard TDRS-1. The maneuvers began on 6 June 1983 and took a total of three weeks. During this time, overheating caused the total loss of one of the two sets of 12 thrusters plus one thruster from the other set.

But the patience paid off. On 29 June 1983, TDRS-1 reached its destination, parking itself over the Equator in a "figure-8" loop at 41° west longitude, just off the northeast coast of Brazil. There was much to celebrate at Goddard. As one flight controller put it, "It was a cliff hanger."[47]

A week later, TDRS-1 was turned on for testing. All went well until October when the spacecraft began to be plagued by a series of component failures. First, one of the Ku-band SA diplexers used to combine RF signals failed. Shortly thereafter, one of the Ku-band TWT amplifiers on the same antenna failed crippling the forward link relay service that it could provide. The failures continued. On 19 November 1983, one of the two TWT amplifiers serving the other SA antenna also failed. This meant that TDRS-1 had lost one of its primary capabilities, the Single Access, Ku-band, forward link relay.

One of the consequences of losing this link was that it prohibited the use of the Text And Graphics System (TAGS) onboard the Shuttle. TAGS was a high-resolution facsimile system that scanned text or graphics and converted the analog scan into a digital bit-stream. Basically, a fancy fax machine that operated via telemetry, it provided an on-orbit capability to transmit text, maps, high resolution schematics and photographs between the astronauts and Houston. In lieu of TAGS, Mission Control—not until 1989 as it turned out—had to resort to using the old S-band, Apollo-era teletype system to relay text-only instructions up to the crew (for example, procedures, weather, crew activity plan changes, etc.).[48]

Despite these annoying setbacks, Goddard continued testing over the next 12 months. The fact that the craft had lost a major link capability notwithstanding, NASA declared TDRS-1 operational in December 1984, saying "Working solo, TDRS-1 provided more communication coverage . . . than the entire network of NASA tracking stations had provided in all previous Shuttle missions."[49]

It had been a long 20 months since TDRS-1 left Pad 39A.

The ensuing years have born witness to this declaration. Besides serving as one of the two primary satellites in the early Space Network, TDRS-1, over the years, accumulated a number of firsts to its credit. It was the first satellite used to support KSC launches in the early 1990s, returning real-time telemetry and video. It also helped close the Zone of Exclusion over the Indian Ocean (explained later in the chapter), providing 100 percent coverage for the ISS, the Space Shuttle and low Earth orbit satellites. In March 1992, Goddard called on TDRS-1 to quickly aid its Compton Gamma Ray Observatory (CGRO) when data recorders onboard the spacecraft failed.

Since the satellite was precessing (that is, changing its orbital inclination or tilt with respect to the Equator) in its orbit almost 1° per year since its deployment, it was used serendipitously in ways never expected. Due to its changing orbit, TDRS-1 was the first satellite able to connect both Poles. In cooperation with the National Science Foundation (NSF), NASA put a ground station for TDRS-1 in January of 1998 at the exact location of the (true) South Pole. The terminal has since given scientists at the Amundsen-Scott Base in Antarctica the year-round ability to return high volumes of science data to the continental United States. With it, the first connection to the Internet—and the first live Web cast—from the North Pole was done as was the first Pole-to-Pole telephone call connecting the North Pole to the South Pole. The event was even recorded in 'Ripley's Believe It Or Not' and the Guinness World Records in April 1999.[50]

NASA considered retiring the aging satellite in 1998, but instead allowed the NSF and others to use it for scientific, humanitarian and educational purposes. For example, TDRS-1 was used in 1998 for a medical emergency at McMurdo Station in Antarctica. Its high-speed connectivity allowed scientists to conduct a telemedicine conference, allowing doctors in the U.S. to teleconference a welder through an operation on a woman diagnosed with breast cancer.

A second working satellite placed into orbit in January 1986 would have meant an operational TDRSS and attendant closure of most ground stations shortly thereafter. Those plans were, however, suddenly dashed when the Space Shuttle *Challenger* met with a horrific demise 73 seconds into its mission on 28 January 1986 (STS-51L). At 11:38 EST that morning, it was launched atop Pad 39B at the KSC in the 36°F chill of the south Florida winter, the coldest ever for a Shuttle mission. The mission was the most publicized NASA flight since Sally K. Ride became the first American woman in space on STS-7 two and a half years earlier. *Challenger*'s crew of seven was commanded by Shuttle veteran Francis R. "Dick" Scobee; joining him were Pilot Michael J. Smith; Mission Specialists Ellison S. Onizuka, Judith A. Resnik, and Ronald E. McNair; and Payload Specialists S. Christa McAuliffe, a high school social studies teacher from Concord, New Hampshire and Gregory B. Jarvis, an engineer with TRW. The primary mission of the planned week-long flight was to deploy and checkout TDRS-2. However, the fact that McAuliffe was going into space garnered the flight more national attention than usual from the media, much more so than on any of the previous 17 missions since STS-7.

From liftoff until telemetry was lost, no flight controller observed any indication of a problem, although post-flight analysis showed telemetry had uncovered some anomalies regarding pressures inside the starboard SRB motor shortly after liftoff. The last voice transmission was received via Ponce de Leon as Scobee acknowledged a routine main engine throttle up call from the Capcom with simply a "Roger, go at throttle up." Three seconds later, a horrified crowd—including many in the crewmembers' families and students who had made the trip from New Hampshire to cheer on McAuliffe—watched, stunned, as *Challenger* erupted into a giant ball of flames.

Many unfamiliar with the Space Shuttle at first thought this was the routine separation of the SRBs. However, the onlookers soon realized that something was happening that was anything but routine when they saw the SRBs emerging from the cloud without any sign of *Challenger*. The crew

The *Challenger* crewmember remains are transferred from seven hearse vehicles to a C-141 at the Kennedy Space Center's Shuttle Landing Facility for transport to Dover Air Force Base, Delaware. The accident that claimed the lives of the five NASA astronauts and two Payload Specialists also set back construction of the TDRSS Space Network by 32 months. (NASA Image Number GPN-2000-001480) apparently had no indication of any problems before the Orbiter rapidly broke apart.[51] No alarms ever sounded on the flight deck. The first evidence of the accident came from live video coverage on the ground and when radars at the Cape began picking up multiple objects.

A Presidential Commission (the Rogers Commission, named after Commission Chairman William P. Rogers, a former Secretary of State in the Nixon administration) was formed by President Reagan on 3 February 1986 under Executive Order 12546 to investigate the accident, which by then had assumed national tragedy proportions. Four months later, the Commission issued its report which included the following conclusion on the cause of the accident:

> The consensus of the Commission and participating investigative agencies is that the loss of the Space Shuttle *Challenger* was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure.[52]

Besides the tremendous shock of having lost a flight crew for the first time on an actual mission—other astronauts and astronaut candidates had been killed before during training and on ground tests—the space agency had to deal with the ramifications of a nearly three-year wait as the Shuttle would not fly again until September of 1988. The launch manifest had to be rearranged. Foremost among the considerations was to resume deployment of the TDRSs as soon as possible. Getting TDRSS operational had an extremely high priority at NASA as its capabilities were needed by so many science application satellite missions and of course, the Space Shuttle itself. The SN simply had to be established as quickly as possible after Shuttle flights resumed. In what is somewhat of a bittersweet irony, the TDRSS program in a way benefited from the *Challenger* disaster in that the hiatus allowed TDRS-1 to be shaken down as a prototype. The added time before the launch of the next spacecraft, TDRS-3, allowed problems with TDRS-1 to be fixed. This probably led to longer useful life of the succeeding spacecraft.

After the accident, Shuttle launches were put on hold indefinitely. Since *Challenger* was to have launched all the early TDRS, NASA used this down time to begin modifying the payload bay of *Discovery* for it to assume this duty. Following the Rogers investigation and an extensive redesign to the SRBs, Return-to-Flight processing finally began in earnest in September of 1987.

On 16 May 1988, TDRS-3 arrived at the KSC from California followed by its IUS eight days later. By the end of May, mechanical mating of the two was complete. The pace picked up from there. On the morning of July 4th, in a symbolic gesture befitting the moment, the entire STS-26 stack was rolled-out of the Vehicle Assembly Building to take the Shuttle's first steps back into space by making its three-mile journey to Pad 39B. Countdown tests were conducted over the next few weeks which revealed some leaks with the Main Propulsion System as well as the Orbital Maneuvering System. However, repairs were successfully done on the pad and on August 29, technicians installed the satellite into *Discovery*'s payload bay. One month later, NASA managers gave the final go-ahead for launch.[53]

At 11:37 a.m. EDT on the morning of 29 September 1988, STS-26, with NASA's most experienced crew to date, took to the skies of eastern Florida. After 32 long months, the Shuttle was back in space, this time flying with redesigned SRB field joints along with other safety and performance upgrades, including for the first time since STS-4, a (limited) crew escape capability. This time, the launch was flawless.[54]

Twelve minutes later, *Discovery* was in orbit. Onboard was TDRS-3. Six hours after reaching orbit, the crew successfully sent it on its way to its geosynchronous destination over the Pacific. NASA had for some time considered not putting the TDRS-3 payload on STS-26 since it was going to be the first mission following *Challenger*. Risk analysis showed, however, that it would have made little difference in terms of probability to mission success whether the payload was launched then or on a later mission since launch risk did not vary significantly from mission to mission. More importantly, getting TDRS-3 deployed was critical for the success of missions down the line.

With TDRS-3 (and TDRS-1) firmly in orbit, NASA finally had its long-awaited, dual-satellite SN capability. The two were referred to as TDRS-West and a TDRS-East, respectively. But the constellation was far from complete. The network called for even more satellites, including on-orbit spares plus a replacement for the one that was lost on *Challenger*. In fact, the original, first generation constellation called for six satellites total. Today, there are nine TDRSS spacecraft on orbit all together.

In the years since, NASA has been criticized (mostly from opposition in Congress) as to why there are so many satellites "up there"? After all, only two are needed to provide 85 percent coverage while three can provide 100 percent. The answer lies in something called "availability of the system." As a communications network, TDRSS, from the beginning, was designed with a very high probability that it would be there when needed. Thus, a very high mark or "figure-of-merit" was put on the system—an assurance that it was going to be available. Former Associate Administrator Charles Force explained what that meant in terms of the number of satellites required:

Table 7-1: First Generation TDRSS Constellation[55]

Satellite	Launch Date Shuttle Mission	Geosynchronous Longitude	Location
TDRS-1 (F1*)	April 4, 1983 STS-6 Challenger	49˚W	Off the northeast coast of Brazil
TDRS-2	January 28, 1986 STS-51L Challenger	—	
TDRS-3 (F3)	September 29, 1988 STS-26 Discovery	85˚E	Indian Ocean
TDRS-4 (F4)	March 13, 1989 STS-29 Discovery	41˚W	Atlantic Ocean east of Brazil
TDRS-5 (F5)	August 2, 1991 STS-43 Atlantis	174˚W	Pacific Ocean over the Phoenix Islands
TDRS-6 (F6)	January 13, 1993 STS-54 Endeavour	47˚W	Off the northeast coast of Brazil
TDRS-7 (F7)	July 13, 1995 STS-70 Discovery	171˚W	Pacific Ocean over the Phoenix Islands

*GSFC designation F1 through F7 represents TDRS-1 through TDRS-7

> There are more satellites and more capacity than you need because you are shooting at that mark. So that mark is what drove the number of TDRSs which were ordered and the replenishment satellites. . . . The reason goes right back to the criticality of it and the need to make sure that the capacity was there when needed. My analogy to a light switch: You turn on a switch and there is a satellite up there to do the job.[56]

Then the issue came up. What should NASA do with all these extra satellites—most of which were not needed yet because of the success of those already in orbit? The answer, in the eyes of the space agency, was quite simple: warehouse (store) them in orbit. Said Force:

> There were some studies done, primarily by TRW . . . which said . . . there's nothing on the satellite that really wears out with use except the solar cells degrade slightly with time, [so] there was plenty of capacity there. The riskiest thing about a TDRS is the launch phase, as demonstrated by the fact that we lost one on *Challenger* and the first one halfway to geosync because the IUS failed. So the decision at that point was, we're better off storing them in orbit because then you get by the infant mortality—the launch failures and all that sort of stuff. So that's basically why there are so many TDRSs up there. If you look at the requirement, hav-

> ing 96 percent probability that you're going to have TDRSS capacity that is needed,…then you have to have x-number of TDRSs. And once you've got them, you might as well launch them and store them on-orbit.[57]

In fact, the operational availability of the TDRSS is not 96 percent but has exceeded 99 percent. This is thus a clear case where the requirement—and not the cost—drove the program.[58]

On 13 March 1989, TDRS-4 was launched on STS-29 again aboard *Discovery.* After successfully attaining orbit, it was slowly positioned as TDRS-East off the coast of Brazil. After that, TDRS-1 was slowly moved to the spare position where it has served ever since on a limited basis under the inauspicious name of WART (White Sands Complex Alternative Resource Terminal), used by the NSF in their research activities at the South Pole.

TDRS-5 followed on STS-43 on 2 August 1991, this time aboard the Shuttle *Atlantis.* Seventeen months later, on 13 January 1993, TDRS-6 was launched on STS-54 aboard *Endeavour.* The last of the first generation satellites, TDRS-7, (included with NASA's *Challenger* replacement fund) went into orbit 13 July 1995 aboard *Discovery* on STS-70. It was the replacement for the one lost on *Challenger.* With it, NASA's first generation TDRSS was completed.

Table 7-1 is a summary of the SN as it appeared during the 1990s. Since the satellites are capable of being repositioned and NASA at times changes their locations so as to maximize network efficiency or to meet specific mission demands, a good way to look at the table is that it shows the locations for a baseline TDRSS constellation.

If one were to take a close look at the satellite locations making up the TDRSS constellation, it can be seen that they are clustered in groups of roughly 130° apart in longitude around the Equator. This spacing is not by chance and has to do with where NASA wanted to put its central network ground terminal.

Take, for example, a case where two satellites are spaced 180° apart in geosynchronous orbit, one over the Eastern Hemisphere and the other over the West. In this arrangement, they would be able to provide complete global coverage. But due to curvature of Earth, however, *two* ground terminals would be required to communicate with them. If this spacing were to be reduced, however, from 180° to 130°, then only a single ground terminal would be needed.

Goddard network planners understood this well and very early on in the program, decided to take advantage of this by locating a single terminal at White Sands in southern New Mexico. The White Sands Ground Terminal (WSGT) provides a perfect line-of-sight vantage point from the western United States where communications with both TDRS-East and TDRS-West could be maintained. To protect physical security, NASA also wanted a location in the continental United States. Finally, like the Mojave Desert of California, White Sands is relatively dry in terms of annual rainfall, which is important since rain can interfere with Ku-band transmission—one of its few disadvantages.

In addition to meeting these requirements, White Sands had also continuously served NASA since 1961. Taken together, the decision to put the TDRSS ground terminal there was really quite logical. It is interesting to note that when the TDRSS Source Evaluation Board (SEB) was deciding between Western Union and RCA as to which would be awarded the contract, it gave the option for both bidders to propose putting the central ground terminal elsewhere, as long as it was within the continental United States. Neither bidder chose to do that, both opting instead to use the government-furnished land on White Sands, the birthplace of America's missile testing activities 30 years earlier.[59]

Located 25 kilometers (16 miles) northeast of the city of Las Cruces, New Mexico, the WSGT is one of the largest and most complex communication terminals ever built. Run by the Space Network Project Office at the GSFC, the WSGT provides the acquisition and relay hardware and software necessary to ensure uninterrupted communications between customer spacecraft in orbit and the NASA Integrated Services Network (NISN) that interfaces to the various spacecraft control centers. In other words, it is the critical hub on the ground that links a user spacecraft to its control center. Without it, data from the TDRSS cannot reach its user and commands cannot be sent up to the satellite.

The NISN provides the critical ground circuits which make the system a true network; without it, TDRSS would just be a collection of satellites and antennas. The ground terminal maintains each TDRS spacecraft in a nominal communication mode (Ku-band) at all times and ensures that all systems aboard the spacecraft are properly configured and functioning properly. It transmits the so-called "forward" link traffic to each TDRS spacecraft for relay to the designated user satellite. Conversely, the ground terminal receives and processes customer spacecraft "return" link, formats and then transmits the data to the NISN interface which carries the data to the rest of the user community.

In addition to providing data services, the health and status of each TDRS spacecraft must be monitored. This is done by flight controllers at White Sands who also track "the birds" in space. As with any large space project, testing and simulation are done on a regular basis so as to evaluate the performance of all the elements that make up the system. For example, "mission sims" are conducted with White Sands sending commands via the tracking and data relay satellites to the user spacecraft, ordering it to perform certain functions and self-test diagnostics. If the tests involve the Shuttle or the ISS, these commands would originate from the JSC in Houston. Otherwise, they

The White Sands Ground Terminal (WSGT) is the central hub of NASA's Tracking and Data Relay Satellite System (TDRSS). It continues the space agency's tracking and data network presence on the south New Mexico Range, a legacy that dates back to 1961. (NASA Image Number HQTC83-907)

would come from the Project Control Centers at the GSFC or the Network Control Center (NCC) at White Sands.[60]

From the outside, the complex is dominated by three 60-foot Ku-band dish antennas. Designated "North," "South," and "Central," they are the link from the ground to the TDRSS spacecraft in geosynchronous orbit 35,900 kilometers in the sky. They handle every aspect of TDRSS transmissions, from voice to television to data. Satellite commands received from various NASA sources are also modulated onto Ku-band frequencies and transmitted to orbit via the system. Because of the extremely short wavelength of Ku-band signals, there is very little room for error. These antennas are extremely precise. Surfaces of these antenna dishes cannot deviate by more than 0.5 millimeter (0.02 inches) from norm (about the width of 20 human hairs) under the extremes of the Southwest desert climate, such as temperatures and winds, plus the loading variations introduced by gravity at various pointing angles. In addition to tolerance, they also have very narrow beamwidths operating in the Ku-band. As a result, Harris had to build them to very fine specifications so that they can be pointed at anytime to within 0.03 degree and track within 0.01 degree accuracy.[61]

The complexity of the system can be illustrated by looking at what goes on inside the TDRSS Operations Control Center, the large building next to the antennas. Satellite command and control functions ordinarily found in the space segment of a traditional communication system are, for TDRSS, performed by the ground terminal. At the heart of the WSGT are the three redundant Space-to-Ground Link Terminals (SGLTs) each of which is supported by one of the Ku-band antennas to transmit and receive user traffic. Here resides over 300 racks of state-of-the-art electronics equipment that handle everything from data routing to precise timing synchronized to the United States Naval Observatory cesium clock to nanosecond—one-billionth of a second—accuracy.

The three SGLTs operate autonomously and are, for the most part, fully redundant. This means that if one of the SGLTs were to fail, then only the TDRS and services supported by that SGLT would be impacted. Breaking down the system even further, each SGLT is capable of providing four, Single Access, forward and return services for customers. In addition to SA services, two of the three SGLTs can support up to five MA return services along with one forward MA service.

From this control center, NASA can schedule TDRSS support for users and distribute the data from White Sands. Also at the ground terminal are several smaller S-band Tracking, Telemetry & Command System (STTCS) antennas. These are used to provide contingency communications to a TDRSS spacecraft in the event of a SGLT failure. They are also used to communicate with the other on-orbit spare satellites. As an everyday analogy, the STTCS is somewhat like the "service elevator" in the back of a five-star hotel that is used for maintenance, whereas the SGLTs are like the main "guest elevators" that go directly from the guest floors to the front lobby. The White Sands ground terminal and satellites are all automatic and receive their operational inputs from the NCC at the GSFC. The NCC is critical to the operation of the system and is in many ways the brain of the system. Several functions are carried out by the NCC: 1) It serves as the user interface and command center of the system. 2) It provides overall management and monitoring of the system. 3) It sets up conflict free schedules and establishes the user unique configuration details (satellite assignment, start and stop times, antenna assignment, pointing information) required for the satellites. To this end, over 40 unique configurable items can be provided by the NCC.[62]

As technically challenging as the whole process seemed, the Agency had good evidence that it was all going to work out. A data relay satellite, ATS-

6, had been used with success in 1975 on the Apollo-Soyuz Test Project. Two years later, on 6 December 1977, the Seasat Program provided for data transmission via satellite from Alaska simultaneously to the GSFC and the Naval Fleet Numerical Weather Center in Monterey California. Even though the data rate was a low 1.544 Mbps, the transmissions served as a feasibility demonstration for the WSGT which would end up using the same types of circuits.[63]

On 17 August 1981, four years after ground break on the project, Ed Smylie, Associate Administrator for Tracking and Data Acquisition, presided over the acceptance ceremony of the White Sands TDRSS Ground Terminal. Other NASA dignitaries included Jesse C. Jones, the new Facility Manager and his Deputy Louis Gomez. The opening of this new communications terminal—the largest of its kind anywhere in the world—was a much needed infusion to the south New Mexico economy which has been tied so closely to the DOD. In 1981, for instance, the value of NASA's contracts and grants to institutions in New Mexico, and White Sands in particular, provided between $20 to $30 million per year and accounted for 600 jobs and 66 contracts in the private sector and universities such as New Mexico State University in nearby Las Cruces and the New Mexico Institute of Technology in Socorro.[64]

With Holloman Air Force Base—operating right outside the gates of White Sands Missile Range—soon to be designated as the home for the Air Force's then most advanced and stealthy aircraft, the F-117A Nighthawk (better known as the Stealth Fighter), the flatlands of Otero County soon boasted some of the most advanced technology found anywhere. Added to this was the diverse work NASA was doing with the Department of the Interior in the use of remote sensing for diverse applications such as timber management, land cover classification, grasslands range management, and deer habitat identification.

On the cultural realm, satellite remote sensing technology supported by TDRSS was used by the National Parks Service to uncover features of prehistoric ruins not visible by conventional aerial photography. As an example, Smylie pointed out in his dedication speech the new insight into the society of the Anasazi Indians that had been gained by remote sensing. TDRSS continues to support Earth science research today.[65]

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With six TDRSS spacecraft now in orbit, the question of reliability and the need to support more than just three operational satellites (TDRS-East, TDRS-West and the spare) became an issue. The WSGT had three antenna systems, perfect for supporting these three operational spacecraft. But now six TDRSs were in orbit all needing support from the ground. This, combined with a host of data-intensive missions that NASA was planning—missions such as the Great Observatories, Spacelab and Spacehab (orbital workshops attached to the Shuttle payload bay), Space Station *Freedom* (the canceled, U.S.-only forerunner to the ISS) and the Cosmic Background Explorer—and the huge amounts of data returned to Earth all pointed to the need for a second TDRSS ground terminal. In August of 1987, NASA approved Project 9717 to construct a Second TDRSS Ground Terminal at White Sands.

The STGT, as it would be called, is identical to the first terminal and is in fact located just five kilometers (three miles) to the north. Its purpose is really twofold: In addition to keeping up with America's spaceflight communication requirements in the 1990s and beyond, it would serve as a backup to the WSGT, eliminating it as a single point of failure in the event of a breakdown or during planned outages for system upgrades and repairs.[66] This point was driven home on 1 September 1983. On that day, controllers were busy checking out the TDRS-1 spacecraft after it had finally made it to its duty station in geosynchronous orbit, when a sudden failure at the WSGT caused a three-hour communication outage with the Shuttle (STS-8). Flight controllers did not wake the crew, however, since all indications through other communication links (transponders were in place which could operate in either TDRS or ground network mode) showed that everything was otherwise normal onboard the vehicle and that this was strictly a communications problem.[67] Nevertheless, it was a good lesson that a backup was needed. In fact, this second ground terminal was considered so important that design specifications called for it to have greater than 0.9999 reliability, or less than one hour per year of down time.[68]

In 1987, the TDRSS program office initiated competitive definition phase studies for the development of a STGT. A year later, General Electric's Military and Data Systems Operations of Valley Forge, Pennsylvania, received the prime contract to build the second terminal. This included all the design, development, installation, and testing of the $245 million worth of communication and computer hardware along with all the software. The $14 million building construction contract was awarded to Argee Corporation, a civil and mining construction company of Denver, Colorado.[69]

As massive as the original, this new terminal also boasted a 7,430-square meter (80,000-square foot) operations building, a 2,320-square meter (25,000-square foot) technical support building and an 830-square meter (9,000-square foot) power plant. Coming on the heels of the *Challenger* accident, and with the rather significant windfall to southern New Mexico economy, ground breaking for the new terminal on 9 September 1987 was quite the public affairs event. Speakers included Robert O. Aller, NASA Associate Administrator for Space Tracking and Data Systems; GSFC Deputy Director John J. Quann; and Captain Frederick H. "Rick" Hauck, Commander of the first mission following *Challenger*. In addition to representatives from State and U.S. Congress, dignitaries included Major General Joseph S. Owens, Commander of the White Sands Missile Range; John P. Stapp and Gregory P. Kennedy from Alamogordo's

Photograph of the Second TDRSS Ground Terminal (STGT) at the White Sands Missile Range in Southern New Mexico. Towering over the main Operations Building are the three 18.3-meter (60-foot) Ku-band antennas. The San Andres Mountains are in the background. (Photograph courtesy of NASA)

own International Space Hall of Fame (one of New Mexico's top tourist attractions); and even archaeologists from nearby Las Cruces.[70]

Before any concrete could be poured, though, NASA had an obligation, this one regarding the environment. In keeping with its federal mandate to protect cultural and natural resources, test excavations had to be conducted near the site of the terminal to see if construction would adversely impact any significant archaeological or historical sites. To this end, the space agency hired the firm of Batcho & Kauffman from Las Cruces to serve as archaeological consultants for this new Space Age project.

Sure enough, excavations soon uncovered Native American artifacts on the site. Further digs revealed that NASA had in fact stumbled onto quite the archaeological find. In their report, the archaeologists noted that: " . . . it soon became apparent that one of the sites contained the undisturbed remains of a pithouse settlement, while the other—located a few miles farther south—contained the remains of a temporary camp, probably once used to gather and process wild foods."[71]

Further research showed these pithouses to be a common type of dwelling used by prehistoric Indians in the Southwest United States. Charred roofing material was also found which carbon dated to some time between 650 and 750 A.D., meaning the site was more than 1,300 years old! In addition to the pithouse settlements themselves, a broad area around the dig was also excavated in what archaeologists call the "activity areas." The completeness of the find was confirmed as the activity areas contained the remains of outdoor camp and cooking fires, as well as large quantities of debris including pieces of broken pottery, several arrowheads and discarded or broken stone tools and the chips of stones leftover from making them. Also found was a large amount of burnt and unburnt animal bones—the last remains of many meals.

Because of the find, NASA had to move to a second, nearby site. It too was excavated. Though not as robust as the first site, a well-preserved roasting pit, about 1,000 years old, was found. Based on information from early settlers in the area, archaeologists were able to trace the find back to the original Mescalero Apaches of the Southwest.

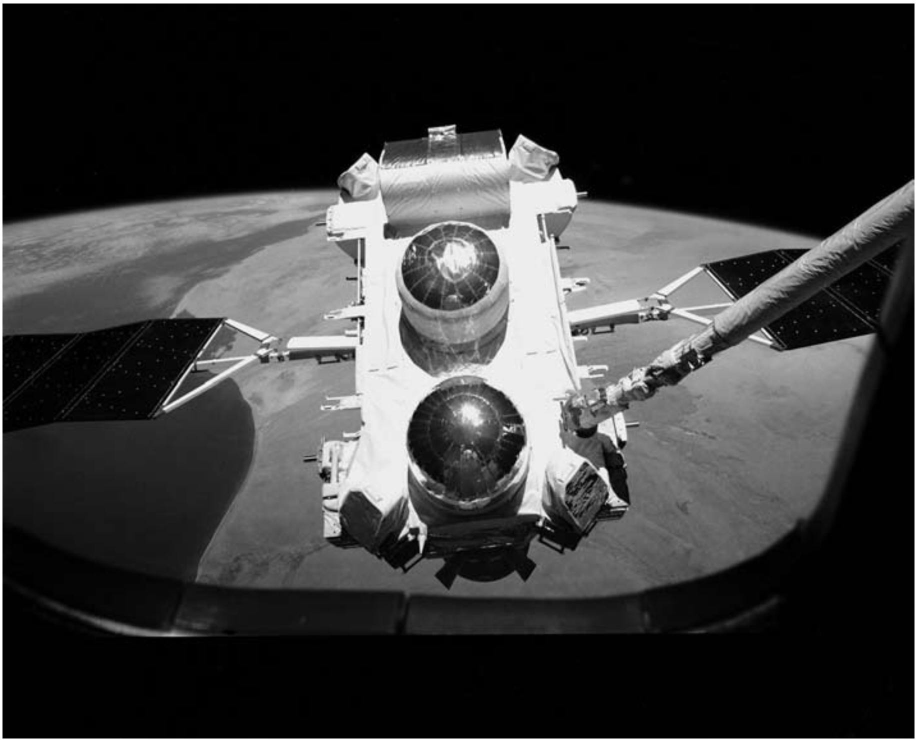
Construction of the terminal eventually embarked on a plot of land near the archaeological find. As serendipity would have it, what started out as NASA simply fulfilling a legal obligation unexpectedly turned into a portal to the past. As one of the archaeologists on the project put it: "While construction is about to begin on this new, high technology facility—to give us another window into space—archaeologists have, likewise, been able to open a small, yet intimate, window into the dim past."[72]

Two and a half years after the ground breaking ceremony, Agency officials once again returned to White Sands, this time to hold a formal ribbon cutting ceremony dedicating the new and second White Sands terminal. Present at the February 1990 ceremony were NASA Administrator Richard H. Truly and his wife; Goddard Center Director John W. Townsend, Jr.; a contingent of New Mexico officials from Albuquerque and Las Cruces; and astronauts John E. Blaha and James F. Buchli, crewmembers of STS-29 that deployed TDRS-4.[73]

With civil construction finished and the new terminal set to open, the Agency wanted something special to tie the White Sands Complex (note the new name) to the Native American and Southwestern roots of New Mexico. After considering several options, the Office of Space Communications, along with the nonprofit New Mexico Space Grant Consortium and New Mexico State University, decided to sponsor a "Name the Ground Terminals" contest.

In keeping with the spirit of the "Land of Enchantment" and the Agency's charter, entries had to 1) Relate to Native American, Hispanic or African American local culture; 2) Be appropriate for space communications and America's involvement in space; 3) Limited to one to two words in length; and 4) Show relationship between the two names. Teams from elementary, middle and high schools in qualifying school districts of southern New Mexico competed. These teams had to abide by some simple rules, such as four students per team along with a team coordinator. Teachers were responsible for guiding their team's activities and for submitting their entry. And each team could submit only two names, one for each ground terminal.[74]

Just as NASA had hoped, the contest proved to be popular, especially among elementary and middle schoolers. More than 100 entries were received. From these, two names—submitted by a team of four girls from Zia Middle School in Las Cruces—were selected: Cacique (kah-see-keh) which means "leader" and Danzante (dahn-zahn-teh) which means "dancer". Roots of the winning names can be traced back to the Tortugas Indians who preserve their culture through traditional dance. In reaching the names, "the students compared the TDRSS to the Tortugas dancers. The dancers com-



The Compton Gamma-Ray Observatory (CGRO) is deployed by the Remote Manipulator System aboard the Space Shuttle Atlantis during STS-37 in April 1991. For nearly nine years, the observatory studied gamma-rays from objects like black holes, pulsars, quasars, neutron stars, and other celestial objects. The information returned has provided scientists clues to the birth, evolution and death of stars, galaxies, and the universe. It reentered Earth's atmosphere and ended its very successful mission in June 2000. (NASA Image Number MSFC-0003356) municate through complex maneuvers as do the TDRSS satellites, [and] the ground terminals are the leaders of this orbital dance," said Wilson T. Lundy, Manager of the White Sands Complex, in an interview after the winning entrants were selected.[75]

NASA was elated. As Charles Force put it, "To those familiar with the culture of the Southwest, these names will give meaning to the purpose of the stations. To those who understand the role of the stations, the names will convey appreciation for the culture of the area."[76] Although the names of the stations were never really embraced by the technical community, the contest was politically successful and had more than fulfilled its purpose.

As for the four girls from Zia Middle School, they received a two-day, all expenses paid trip to tour the JSC in neighboring Texas. In a ceremony on 17 May 1993, the names for the White Sands terminals were officially announced, with presentation of awards to the students by retired Apollo 8 Commander and Las Cruces businessman Frank Borman. A year later, the Danzante terminal was accepted by NASA and declared a fully operational part of the TDRSS.

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On the morning of 5 April 1991, the Shuttle *Atlantis* took off on a six-day mission, the highlight of which was deployment of the CGRO. Named after Ohio Nobel Prize laureate Arthur Holly Compton for his research demonstrating the particle behavior of electromagnetic radiation, the second of NASA's "Great Observatories" to be launched into space, the CGRO, at 17 metric tons (37,500 pounds), was the heaviest astrophysical payload ever flown into space.

The Great Observatories of NASA were four of the largest and most powerful space-based telescopes ever put into orbit. Each was similar in terms of its size, cost and scope of the program, and all have since made a substantial contribution to our understanding of the deep space environment, greatly expanding our knowledge of the known universe. Each of these four space-based observatories was designed to investigate a specific region of the electromagnetic spectrum.

Undoubtedly the best known of the four is the first one to be put into space: the $1.5 billion Hubble Space Telescope (HST). Launched aboard STS-31 on 24 April 1990, the HST primarily observes the visible spectrum. Besides the incredible photographs that have since come from the telescope, it also received a lot of media scrutiny early-on over its "blurred vision," a manifestation of a manufacturing imperfection in which the objective mirror was ground too flat by 2.2-microns, or 1/50th the width of a human hair. Demonstrating the irreplaceable value of human spaceflight, this error was corrected when the crew of STS-61, over the course of four spacewalks, installed and checked out corrective optics to the telescope in December 1993.

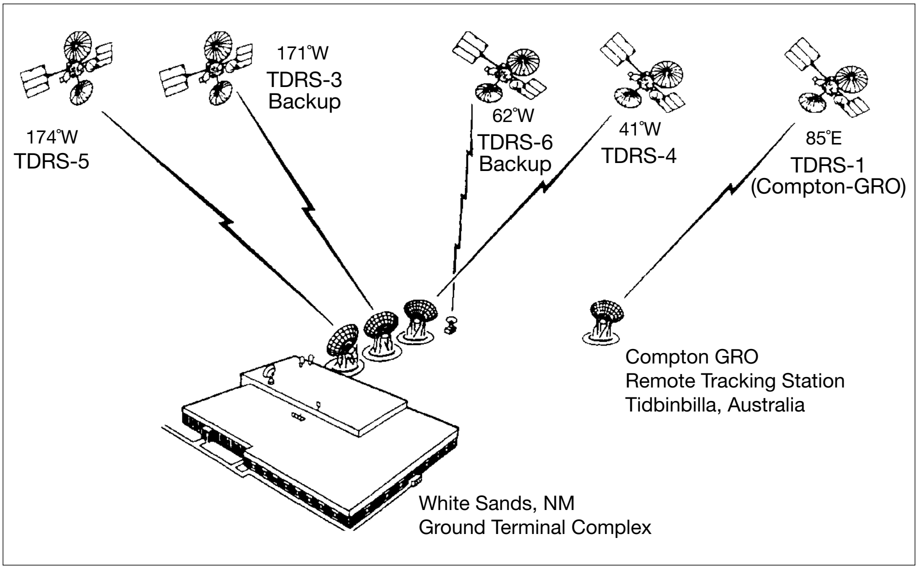
Besides the HST and CGRO, there is the Chandra X-ray Observatory, launched on 23 July 1999 aboard STS-93 and the Space Infrared Telescope Facility (SIRTF) whose primary mission, as its name implies, is observation of the infrared spectrum. (The SIRTF, launched on 25 August 2003 aboard a Delta II rocket, was later renamed the Spitzer Space Telescope.)[77] Aside from performing each telescope's own mission, most of which cannot be replicated by ground observatories, the Great Observatories program allows the four to synergistically interact with each other for greater combined scientific returns. Each astronomical object in the sky radiates in different wavelengths. But by training two or more observatories on an object, combined data can be returned to paint a much more comprehensive picture than is possible with just a single instrument.[78]

After its deployment from STS-37, the CGRO operated as advertised for almost a year, returning more data on that portion of the electromagnetic spectrum than the previous six decades put together. But in March 1992, it suffered a failure of its two onboard tape recorders which restricted downlinks of scientific data to real time only. With the tape recorders gone, CGRO was able to relay only slightly more than half of the science data it collected, because it could not point at a TDRS all the time.

While TDRSS coverage had been about 65 percent of each orbit, scientists could not even collect that percentage of data anymore because Compton's instruments had to be turned off during the part of each orbit when it passed through the elevated background radiation of the South Atlantic Anomaly—a region of significantly increased space radiation experienced by satellites passing over the South Atlantic Ocean.[79] This reduction in data return presented an obstacle to the Goddard science team. NASA, understandably, wanted to get back to the point where all of the data could be retrieved. Furthermore, real-time data dumps could only be done at the very slow rate of 32 kilobits-per-second whereas the playback rate was 512 kilobits-per-second.[80]

Considering all these factors, in March 1992, Goddard's Mission Operations and Data Systems Division was tasked to study approaches to solve this problem utilizing any combination of ground or space resources available. Analysis quickly ruled out an independent, Compton-only, ground station as a solution due to potential high cost with a relatively small increase in additional coverage. An on-orbit Shuttle repair was also looked at but proved too costly, even if just one time. But the same study showed that a TDRSS solution could produce (up to) full, 100 percent coverage for the Compton observatory.[81]

The solution was this. One of the existing TDRS spacecraft had to be moved and located somewhere over the Indian Ocean. Despite the fact that TDRS-1 was near the end of its 10 year design life, it was apparent that its remaining functionality—fuel, health, and condition of onboard instruments—was still meeting the requirements needed for an Indian Ocean satellite. Since this location could not be viewed by the White Sands Complex



The first generation Tracking and Data Relay Satellite System (TDRSS) constellation as it appeared in 1994, with five orbiting satellites—two operational and three backups—in communication with the White Sands Ground Terminal (WSGT) and the GRO Remote Terminal System. (Space Shuttle Mission STS-54 Press Kit, January 1993, NASA Headquarters)

(being inside the so-called Zone of Exclusion from North America), the solution was to consider a ground terminal which could see a TDRS spacecraft if placed over the Indian Ocean.

The existing DSN sites at Madrid and Canberra could observe the TDRS and were thus (initially) the prime candidates. Of the two, Canberra had a slightly better line-of-sight. In addition, it had the advantage of being located in an English speaking country and had a NASA-like culture in its operating infrastructure, the Australian Space Office (ASO). Other ground locations were examined too, for example eastern Africa, but were disqualified mainly because they were not under direct NASA control.[82]

Following completion of the study that summer, Goddard sent out a site survey team, which along with members of the ASO, visited five sites throughout the commonwealth. Reminiscent of the old STADAN days, the team considered such factors as existing hardware, accessibility to long distance communications, transportation and overall logistical support requirements. Based on this survey, the NASA site at the Canberra Deep Space Communication Complex (CDSCC) was selected. The pace of establishing the site was of a high priority since a period of "best science" solar activity was then fast approaching.

The $12 million, GRO Remote Terminal System (GRTS) project was started without delay on 1 September 1992. Scheduled for completion in 13 months, the station was built leveraging maximum use of existing equipment. Essentially all of the TT&C equipment was transferred from existing resources at other Goddard facilities. Redundancy in design was exploited, to the extent feasible and practical, so as to attain good mission assurance. In addition, the TT&C equipment used was purposely identical to the existing equipment on the CDSCC Deep Space side so that any additional training, repair and logistics would be minimized. All of the remaining hardware, such as the 9-meter (30-foot) S-band and 5-meter (16.4-foot) Ku-band antennas, were bought using existing, commercial-off-the-shelf (COTS) designs. In fact, the overall design of the GRTS was based on that recently used to complete the STGT at the White Sands Complex.

With the help of Raytheon Service Company as the procurement agent and Allied Signal Technical Services Corporation providing technical support, Goddard was able to complete the entire procurement process—specifications, solicitations, and negotiation—by January 1993. The Australian contribution was significant too, as all of the construction was done in four months. This included two antennas, two new S- and Ku-band transmitter buildings and a two-kilometer fiber optic cable-run to a remote calibration site—an amazing feat in that amount of time.[83]

On 29 November 1993, White Sands sent a series of commands to begin drifting TDRS-1 from its location over the Phoenix Islands in the Pacific to the Indian Ocean. The trip took 73 days. A week later, the nearly completed GRTS at Tidbinbilla made first contact with the satellite. Then on 9 February 1994, commands were sent to stabilize the spacecraft at its duty station 85° East longitude over the middle of the Indian Ocean. TDRS-1 was now perched atop the Eastern Hemisphere and NASA finally had a truly global SN. Data from the Compton was received by TDRS-1, downlinked to Tidbinbilla, relayed up to an Intelsat commercial satellite where it was downlinked to a commercial terminal on the West Coast and then routed to White Sands. From there, the data was distributed to scientists around the world. Control of TDRS-1 and the Tidbinbilla ground terminal remained at White Sands, marking the first time NASA controlled an out-of-view TDRS from that location.

On 14 March 1994, the Agency officially announced the opening of the new, remote ground station in Tidbinbilla, Australia. "With activation of this ground facility, the TDRS System can, for the first time, provide global coverage," said Charles Force in declaring the new TDRSS station operational. "While the new ground station is devoted to Compton at this time, it has the potential for use by other Earth-orbiting spacecraft."[84]

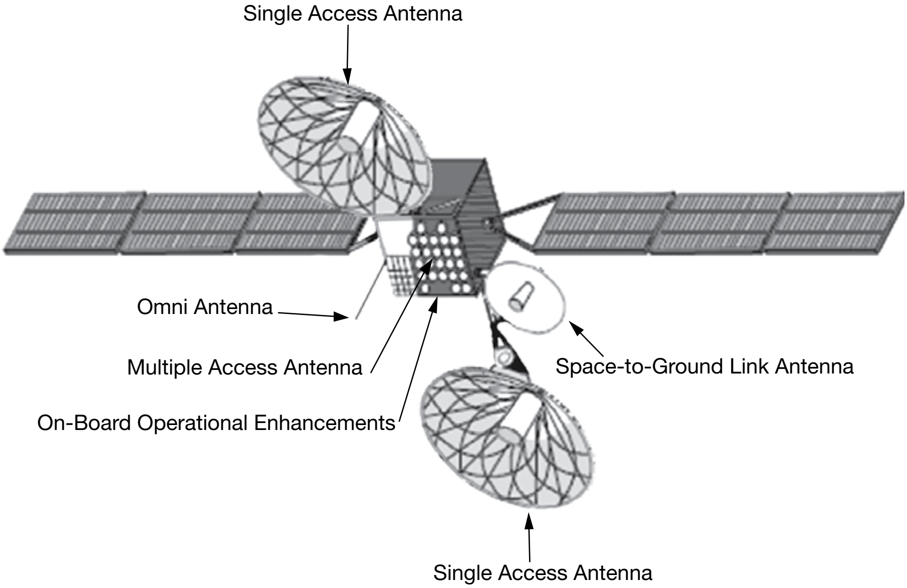
Compton scientists were elated. Frank J. Stocklin, a mission manager at Goddard compared the added capability to the repair of the Hubble Space Telescope:

> We're very pleased that this project came in on budget and on time and that we are able to collect additional, significant data from Compton in a cost-effective manner. It's difficult to place a dollar value on the additional science data obtained in this effort, but the restoration of data recovery capability is similar to that done for the HST, and marks the second successful recovery of a major NASA observatory.[85]

Almost immediately, Compton scientists saw a 30 percent jump in data returned from their observatory. As useful as the Tidbinbilla station at the CDSCC was, though, it still had its fair share of drawbacks. First, the location resulted in a lower than desirable elevation look angle to the TDRS in orbit. Another problem was related to the inability of TDRS-1 to point its Space Ground Link (SGL) antenna far enough south to Canberra to maximize the coverage duration for users besides just the Compton observatory. While not a serious problem, another location could be better. Then there was the cost factor. The ongoing grip of a fiscal mandate to reduce annual maintenance and operating costs required some form of ground station automation. And finally, there was the geopolitical factor. While the British Commonwealth is among the strongest of America's allies—cooperation of Australia with NASA had been impeccable since the days of Minitrack—the United States wanted something as important as an overseas TDRSS ground terminal on American soil, if at all possible. TDRSS had become a national resource. Although not a military asset, the missions and programs it supported had national security implications. A "U.S. territory-based solution" was highly desirable.

Guam, once again, stood out. In addition to being a longtime U.S. territory, there is the stability offered by virtue of having key DOD presence on the island. From its location in the Mariana Islands, Guam is closer to the Equator and longitude to a TDRS spacecraft over the Indian Ocean, allowing it to accommodate much higher antenna elevation angles than is possible from Australia. Besides, the Agency had only just left the island in 1989, finally closing down the Guam STDN station after 24 years as one of the most successful stations in the history of the Agency's networks. Thomas A. Gitlin, Goddard's former ground terminal Project Manager summarized it concisely: "NASA built the Guam ground station to significantly expand the quantity and quality of services we provide to all our customers."[86]

In 1995, NASA was ready to begin funding for a new Guam Remote Ground Terminal, or GRGT. With the acceptance of the second terminal at White Sands the previous year and the launch of TDRS-7 to complete the



Multiple Access Antenna

- 32 receive antenna elements
- 15 transmit antenna elements
- S-band communications:
  - 2.1064 GHz (Forward)
  - 2.2875 GHz (Return)
- LHC polarization
- ±13° conical Field-of-view

Single Access Antenna

- Tri-frequency communications:
  - S-band: 2.025–2.120 GHz (Forward), 2.200–2.300 GHz (Return)
  - Ku-band: 13.775 GHz (Forward), 15.0034 GHz (Return)
  - Ka-band: 22.55–23.55 GHz (Forward), 25.25–27.50 GHz (Return)
- Circular polarization (LHC or RHC)
- Field of View:
  - Primary: ±22° E-W, ±28° N-S rectangular
  - Outboard: 76.8° E-W
  - Inboard: 24° E-W
  - Extended: ±30.5° N-S elliptical

Space-Ground Link Antenna

- 2.4m Ku-band antenna:
  - 14.6–15.25 GHz (uplink)
  - 13.4–14.05 GHz (downlink)
- WSC/GRGT-TDRS uplink/downlink
- Orthogonal, linear polarization
- Modified frequency plan allows collocation

Enhancements

- On-board SA antenna control
- Autonomous recovery from anomalies
- Improved monitoring

Omni Antenna

- S-band TT&C
- LHC polarization

The second generation Tracking and Data Relay Satellite. (TDRS-H, I, J). (Adapted from Space Network User's Guide, SNUG-450, Revision 8, NASA Goddard Space Flight Center) satellite constellation, $9 million of SN funds became available for this project. The remaining $12.4 million needed (for a total of $21.4 million) also came from within the SN program office, but in two parts—from phase-down of the Compton GRTS in Tidbinbilla and from an unexpected source: greater-than-anticipated reimbursements by the Columbia Communications Corporation for revenues from their agreement with NASA for the lease of excess C-band services on the TDRSS. This last point could be called the "remnant" of the Western Union debacle, albeit a positive one. Under the original TDRSS contract, a reimbursable, long-term plan for using the commercial capability built into the original Western Union TDRS design was negotiated. Despite a long, drawn-out, legal process to recover the expected commercial reimbursement (involving the Small Business Administration and the courts), the nightmarish process did eventually return funds to the Agency and was a good use for a C-band system that was otherwise totally superfluous.[87]

The GRGT was designed from the beginning to be a fully automated, remote station, identical in most respects to its White Sands counterpart in the United States. Situated on the secure grounds of the Computer and Telecommunications Area, Master Station Receiver Site of the U.S. Navy base, the station is distinguished by two large radomes which enclose the 5-meter (16.4-foot) Ku-band and 9-meter (30-foot) S-band antennas, protecting them from the typhoons of the central Pacific. Equal in performance with the terminals in New Mexico, the Guam terminal provides relay services in the form of two S-band and two Ku-band forward and return links. High rate, forward service to customer satellites is done at 25 million bits-per-second (Mb/s) while the return service rate is double that, at 50 Mb/s.

Three years after getting the go-ahead, the GRGT was officially opened in a ribbon-cutting ceremony held on 15 July 1998. Although Governor Guerrero was not present this time, the legacy he helped set in bringing NASA's first tracking station to the island three decades earlier had, in a way, come full circle. With the Guam terminal operational, the SN's Zone of Exclusion was closed and TDRSS could now provide 100 percent coverage regardless of where a satellite is in low-Earth orbit. With the project completed, the original Compton remote terminal in Tidbinbella was shut down as planned.[88]

★ ★ ★

Even before the first TDRS was deployed by the crew of STS-6 in April 1983, NASA was already planning for the day when the original TDRSS spacecraft would need to be replaced or replenished after their projected 10-year service life expired. The space agency (and space communications in general) could take advantage of an increase in capabilities brought on by a more advanced, second generation of TDRSS spacecraft. A big factor was that with TDRS-1 through 7, communication links for the Space Shuttle, the HST and its Great Observatory companions, and other Earth-orbiting space missions are limited to the S- and Ku-bands.

In 1981 and 1982, the Office of Space Tracking and Data Systems (OSTDA) conducted a "Prephase A Advanced Study" to look at an advanced TDRS System in which communications would utilize the even more efficient Ka-band of the radio frequency spectrum. Even at that time, the increasing number of users in the S-band was starting to crowd that part of the RF spectrum. It was obvious that the congestion was only going to get worse as the number of satellite users increased in the coming years. With the second generation—or TDRS-II—spacecraft, users would be able to take advantage of Ka-band links to transmit at higher data rates. Along with the higher frequency, smaller antennas could be used than those required at Ku-band—just like smaller antennas are required for Ku-band compared to S-band (and VHF before that).[89]

Following the cessation of all Shuttle flights that ensued after *Challenger*, a Phase A Preliminary Analysis for the TDRS-II was conducted, even as the initial satellite constellation was still being completed. A Phase B Definition Study followed in August of 1990. With this year-long study, specific requirements of a TDRS-II spacecraft were defined, along with specifications and a roadmap of the potential migration of services to the Ka-band. Issues which would affect this migration of services to Ka-band were addressed, such as availability of commercial off-the-shelf space-qualified antennas and equipment with acceptable performance, weight, size, power consumption, and cost. On the user end, the study looked at the development and qualification of customer antennas which would be needed.

The replenishment program would have three TDRS-II spacecraft—designated TDRS-H, I and J—that would support customer services currently provided by TDRS-1 through 7. The three new satellites would be functionally equivalent to the original spacecraft with the exception of the added Ka-band communications capability and an improved MA capability. But there was a major difference, one primarily philosophical. The original TDRS spacecraft—not including TDRS-7—hosted a Ku-band commercial payload which was to have been used by Western Union but was never activated, and a commercial C-band antenna and payload package, two of which are operated by a commercial service provider. To stay far away from the "shared system" approach this time, TDRS-H, I and J were dedicated from the beginning to NASA missions and did not include a commercial Ku or C-band payload. To minimize impact to the user community, the spacecraft was designed such that Ka-band used the same SGL design that the original Ku-band used. In this way, transmissions at the new frequency were essentially transparent to the ground station.[90]

Looking like a high-end version of the original spacecraft, the second generation TDRSS spacecraft was still dominated by two 4.5-meter

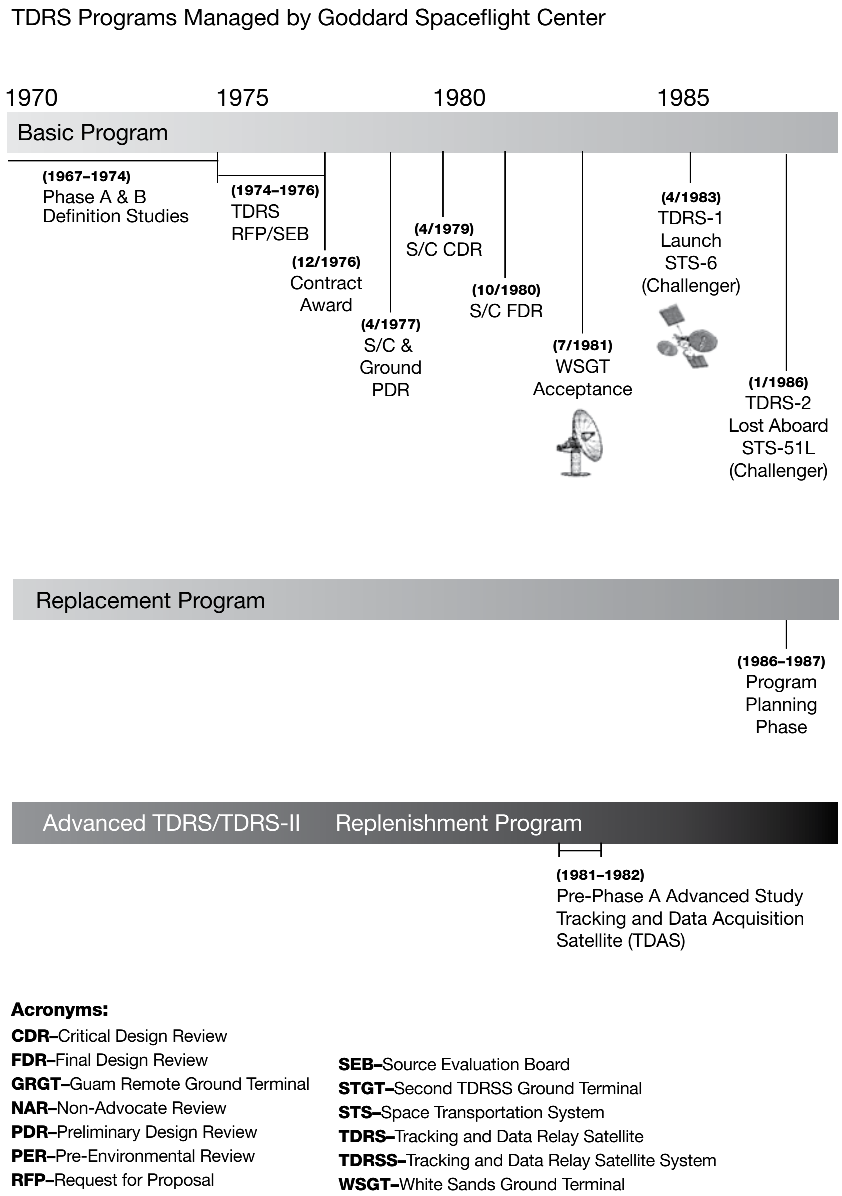
(14.8-foot) diameter steerable SA antennas and a pair of wing-like, solar arrays spanning almost 21 meters (68 feet) from one end to the other. But with a fully-fueled launch weight of 3,175 kilograms (7,000 pounds), it was nearly 900 kilograms (2,000 pounds) heavier than the original.[91] Based on the then newly developed Hughes Spacecraft 601 bus structure, the electrical power,

TDRS-H, I, and J could provide over two and a half times the data relay capability of its predecessors by using Ka-band and other new features. (Photograph courtesy of NASA, *www.gsfc.nasa.gov/topstory/20021127tdrs_j.html*, accessed October 2, 2005) attitude determination and control system, and the TT&C units were all mounted on the central bus structure, as were the solar arrays.

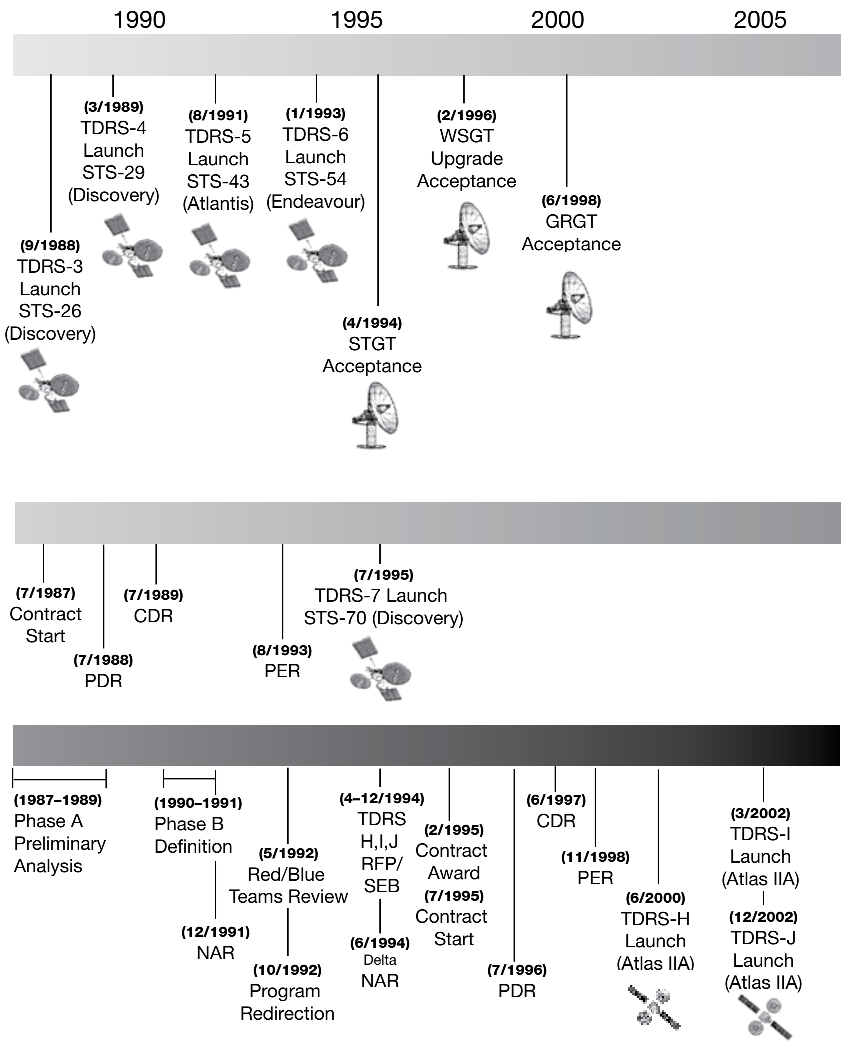
While the original TDRS used hydrazine monopropellant, the new spacecraft now used the higher performing bi-propellant combination of monomethyl hydrazine fuel and nitrogen tetroxide oxidizer for attitude control and main propulsion. This was a proven propellant combination that has been used in the Apollo spacecraft and the Space Shuttle. The RCS used this propulsion system to feed a 110-pound thrust (490-newton) liquid apogee kick motor (used for orbit insertion), along with four 2-pound thrusters (9-newton) and eight 5-pound thrusters (22-newton) mounted around the periphery of the main spacecraft bus to support on-orbit operations over its 15-year service life.[92]

In addition to the RCS jets, attitude control was passively maintained using a gimbaled momentum wheel for three-axis torquing and angular momentum "storage." Continuously operating gyros—updated by Earth and Sun sensors on the spacecraft—provided highly accurate, three-axis attitude sensing to point the spacecraft and its antennas in the proper attitude

Unlike the first generation of Tracking and Data Relay Satellites, TDRS-H, I and J were launched using expendable launch vehicles. Here, TDRS-H rises from PAD36A, Cape Canaveral Air Force Station at 8:56 a.m. EDT on 30 June 2000 atop an Atlas IIA/Centaur launch vehicle. The new satellites augmented TDRSS's existing S- and Ku-band capabilities by adding a Ka-band capability. (NASA Image Number KSC-00PP-0825)



Chronology of the NASA Tracking and Data Relay Satellite System (TDRSS), from concept to reality. (NASA Goddard Space Flight Center)


1990
1995
2000
2005
(9/1988) TDRS-3 Launch STS-26 (Discovery)
(3/1989) TDRS-4 Launch STS-29 (Discovery)
(8/1991) TDRS-5 Launch STS-43 (Atlantis)
(1/1993) TDRS-6 Launch STS-54 (Endeavour)
(4/1994) STGT Acceptance
(2/1996) WSGT Upgrade Acceptance
(6/1998) GRGT Acceptance
(7/1987) Contract Start
(7/1988) PDR
(7/1989) CDR
(8/1993) PER
(7/1995) TDRS-7 Launch STS-70 (Discovery)
(1987–1989) Phase A Preliminary Analysis
(1990–1991) Phase B Definition
(12/1991) NAR
(5/1992) Red/Blue Teams Review
(10/1992) Program Redirection
(4–12/1994) TDRS H,I,J RFP/SEB
(6/1994) Delta NAR
(2/1995) Contract Award
(7/1995) Contract Start
(7/1996) PDR
(6/1997) CDR
(11/1998) PER
(6/2000) TDRS-H Launch (Atlas IIA)
(3/2002) TDRS-I Launch (Atlas IIA)
(12/2002) TDRS-J Launch (Atlas IIA)

in the weightlessness of space. Since the nature of Ka-band transmissions required a narrower beam and thus tighter pointing accuracy than Ku or S-band, the rate gyros used on TDRSS-II were much more robust and had significantly fewer moving parts (that can wear out) than those on the first generation satellites.[93]

Integrated into the main bus structure was a system of heat pipes, multi-layer insulation, radiators and thermostatic heater controls that provided thermal control to the spacecraft—a necessity in the harsh environment of geosynchronous orbit. Then there were the two wing-like power arrays covered with silicon solar cells designed to last 15 years. They provided approximately 2,300 watts of power, enough to light some 30 common household light bulbs. Besides providing electrical power to the spacecraft, they also charged four nickel-hydrogen battery packs which supplied power when the spacecraft was in darkness.[94]

Just like the first generation TDRS, the most prominent part of spacecraft H, I, and J were the two, mechanically steerable SA antennas. Made of a flexible, graphite reinforced, epoxy mesh, the antennas were furled into a taco-like shape and stored for launch. Once deployed, they unfurled and with an innovative "spring-back" design, fine adjustments could be made to compensate for on-orbit changes in the dish contour from things like heating and cooling in the vacuum of space. The SA antennas used a tri-band electronic feed—the device at the focus of the antenna which receives and transmits signals—to accommodate frequencies in S-, Ku- and Ka-bands. With S-band, user satellites with lower gain (less sensitive) antennas, or MA users temporarily requiring an increased data rate, could be accommodated.[95]

It was used, for instance, to support human missions, science data missions such as the HST, and satellite data dumps. With Ka-band, higher bandwidth items such as high-resolution digital television—including all Space Shuttle video—could be relayed. Also, more transmission traffic and higher volumes of data could be dumped to the ground. Finally, with the significant increase in transmission performance (so called "figure-of-merit" increase) afforded by Ka-band, transmission rates approaching the realm of a billion bits-per-second (1 Gbps) were possible. At the TDRS-II specification of 800 million bits-per-second, it was over two and half times faster than what was possible with the original TDRS operating at Ku-band.[96] Again using the encyclopedia analogy, that was somewhat akin to downloading ten 20-volume encyclopedias each second.

Requests for proposals to build the three next generation satellites were issued in April of 1994. After a six-month evaluation, the SEB consisting of members from GSFC and NASA Headquarters presented its recommendation to the Source Selection Official, Charles Force. Force and the SEB were convinced that Hughes Space and Communications of Los Angeles (now Boeing Satellite Systems after its acquisition in 2000) was the best contractor for the job. Not wanting a repeat of the whole Western Union affair, the agency this time went with a well-established satellite manufacturer and the producer of the commercially proven 601 spacecraft bus design. (Founded by billionaire aviator Howard R. Hughes, Jr., the company was in fact the world's largest supplier of commercial satellites in 1995.)

Work started in July, five months after the official announcement. This time, the progress was smooth. Over the next two years, the contractor worked with GSFC to move TDRS-II from a set of requirements onto the drawing table and finally into a design which would fly. After passing the Critical Design Review in June 1997, the pace picked up as manufacturing and testing on the first new satellite, TDRS-H, entered final production.[97]

One major difference between the second generation TDRS spacecraft and their predecessors was in the way they went into space. The original TDRS were launched by the Space Shuttle exclusively. In a move that can still be traced back to the *Challenger* accident, TDRS-H, I, and J were launched by an intermediate class of expendable launch vehicles, the Lockheed Martin Atlas II-A. Developed to fulfill an expendable launch vehicle requirement to supplement United States launch capability following the accident, the Atlas II-A, along with its variants, was a two-and-a half stage liquid propellant rocket. (The Centaur upper-stage was a so-called "half stage" since it was used to position the payload into a separation orbit after booster burnout.) Following separation from the Atlas, the TDRS spacecraft was injected into its final orbit using its own apogee kick motor.

Launch services using the Atlas II-A were finalized as early as 1997. Nearly three years later, the new TDRS-II spacecraft was ready. On 30 June 2000, TDRS-H successfully lifted off from Launch Complex 36 at Cape Canaveral. Since the satellite was not launched by NASA, Boeing had the overall responsibility to make sure that it got onto orbit as advertised prior to the Agency taking control. It attained orbit without any problems. Its acceptance by NASA was delayed, though, due to lower than expected performance of the new MA phased array antenna. As a result, ground controllers discovered that 5 of the 18 communications services provided by TDRS-H performed at less than full capability.

This degradation puzzled both Boeing and NASA since the spacecraft had checked out perfectly on the ground. After a month of troubleshooting, the culprit was found. Randy H. Brinkley, President of Boeing Satellite Systems explained at the time that the hidden problem was traced back to a material defect. "We identified the cause of the problem to be rooted in one specific material used in the assembly of the antenna and implemented straightforward corrective measures for TDRS-I and TDRS-J. We are certain that a repeat of this performance shortfall will not occur."[98]

Manufacturing changes were implemented and 18 months later, on 8 March 2002, the next spacecraft was launched. This time, it performed flawlessly. TDRS-I was followed into orbit 9 months later with the launch of the final satellite, TDRS-J, on 4 December 2002.

The three satellites were initially launched into their on-orbit "storage locations" over the Phoenix Islands in the mid-Pacific; off the west coast of South America near Ecuador; and off the Brazilian coast over the Atlantic. There, the satellites stayed, almost in a "garaged" fashion, until they were needed. The advantage of having these spacecraft in orbit was that the Explorations, Operations, Communications and Navigation Systems Division of Goddard, who manages the SN, may change the geosynchronous location of any TDRS to any other geosynchronous location assigned to NASA. This allowed collocation of two spacecraft in one longitudinal setting. Two second generation spacecraft could be located together, if needed, or one first generation with one second generation. This was quite useful and allowed the use of two partially failed spacecraft to be collocated to conserve the limited slots available at geosynchronous altitude and to pool together their capabilities.[99]

With TDRS-II available, the SN was much more flexible and more options could be exercised to optimize the TDRSS network for all users. A case in point was a high data rate user such as a remote sensing mission with large amounts of imaging data. This satellite, which could have onboard several bandwidth-intensive instruments, may generate up to three-*terabits* (3,000,000,000,000) per day of science data. On top of that was the required "overhead" information such as data for link protocols and error correction coding, adding another 16 percent or more to the raw science data.[100] With the first generation TDRS, it would have taken over three hours each day just to transfer this data from the spacecraft to the ground. A Ka-band TDRS-II SA link at a rate of 800 Mb/s reduced this to about 72 minutes per day. NASA may schedule this data transfer in a number of ways. For instance, 5 minutes of TDRSS service for every orbit of a satellite or 10 minutes of service on every other orbit. If the data was time sensitive, Ka-band service allowed for near instantaneous availability of the data to its users, much more so than with the original system. While S- and Ku-band capabilities also provided near instantaneous services, they required significantly longer transfer times.[101]

Now consider the case of a small, low-data rate user such as a single instrument satellite. It too wanted to use the TDRSS to get data to the ground. Although low-data rate users did not require the wide bandwidth channels available at Ka-band, they *could still benefit* from Ka-band services in terms of antenna requirements. Take a small low-Earth orbiting spacecraft that had only one or two low data rate instruments. It may generate only 20 gigabits (20,000,000,000) of science data per day. Ka-band MA service at 4 Mb/s could transfer all that data in less than 7 minutes on each orbit or 13 minutes on every other orbit. In this case, the user only needed a very small 10-centimeter (4-inch) diameter parabolic dish or a phased array antenna on his satellite. Although small, the parabolic dish would still require a tracking mechanism to keep it pointed at the TDRS spacecraft. On the other hand, a phased array antenna would have been especially beneficial since the absence of a steearable antenna greatly simplified attitude control of the user satellite and minimized moving parts on the spacecraft.[102]

NASA now had its long awaited TDRSS. With it, the expansive network of worldwide ground stations seemed to be a thing of the past. Gary A. Morse, former Network Director at Goddard's Network Control Center, reflected on the change TDRSS brought to those who worked on NASA's spaceflight tracking networks:

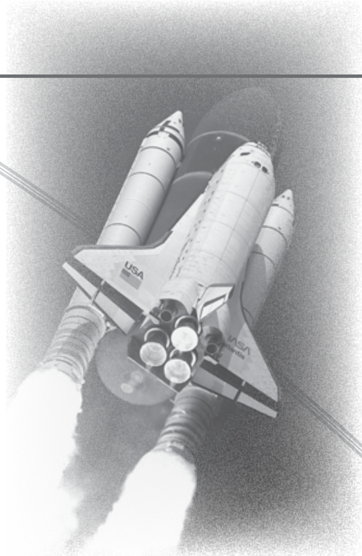
> The concept of the SN was culture shock. Here, instead of a worldwide net of ground stations, we had two satellites looking down and providing 85 percent orbit coverage, continuous command and telemetry. We were no longer confined to six-minute passes over stationary ground equipment. We had to learn an entirely new technology and apply it. With the old ground net, we had to rely on redundancy. This switch fails, the backup is activated by an operator reaching over and flipping another switch. The new SN was less real-time redundant than the GN had been. We had relied heavily on that redundancy to remain transparent. Any mission was about the spacecraft that was flying, not on what might be going on inside the tracking network. It's our job to focus on the mission . . . The network was there to serve the user, to serve the guy that's flying his spacecraft . . . We might be launching and flying fewer spacecraft now, but those in orbit and the ones planned for launch were more complex. Data rates were higher. The stakes were higher.[103]

As passé as the ground network may have seemed at the time, the advent of TDRSS did not eliminate ground stations all together but merely transformed them into a different role. The GN was supposed to have been shut down with TDRSS and the SN was supposed to have taken on the load for near-Earth activities. But it did not quite happen that way. One reason was that a satellite with fairly high data demands still had to have a steerable dish in order to communicate with a TDRS. That was an expensive thing to put on a satellite, even today. To get around this, the satellite could instead downlink to a ground station using only a fixed, much cheaper antenna since a ground station was much closer—only some 1,000 kilometers or 600 miles away—rather than the TDRS orbiting 35,900 kilometers (22,300 miles) overhead.

Users, including NASA itself, understood this. It was inherently less expensive for many cost-constrained, particularly Earth science missions, to build small ground stations dedicated specifically to support their own missions. Many of these places were either unattended or minimally attended stations (for safety) to further reduce cost. Since the TT&C service *was* the MA service and TDRSS could provide that at anytime and anywhere, an interesting synergy developed. Satellites quite often downlinked their high rate science data to their ground station but still used the TDRSS for the lower data, lower cost MA capability to monitor its health and status.[104]

No longer would a STDN ground station be used to track a spacecraft orbiting around Earth or to talk to astronauts in space. Ground stations now had a new mission, and that mission could be summed up in one word: Science. With TDRSS operational, there was no longer the need for ground stations to assume the role of the traditional "tracking station." Emphasis of a GN was now on data acquisition at remote outposts and rocket ranges to support range safety, Earth science and space research. This paradigm shift in the role of the ground stations soon made NASA a key player in what became the commercialization of space, taking the Agency to ever more remote regions of the globe, even to the North and South Pole.

CHAPTER 8



THE NEW LANDSCAPE

An operational TDRSS did not mean that a GN was not needed. It still was, just not in the same way as before. Phase out from the STDN organization did not put an end to NASA's ground station activities. Many sites operated like they did before TDRSS came along, only now they did so for different reasons. No longer called the STDN, the GN played a different role to support a different mission.

In the Pacific, the Kauai Station supported the University of Hawaii specifically, and the Earth science community at large, operating as the Kokee Park Geophysical Observatory (KPGO). As far back as 1981, operations at Kauai had reduced from 24/7 around-the-clock operations to a standard eight-hour, five-days-a-week schedule. Like many of the stations in the network, Hawaii had seen its fair share of "close calls" when it came to closing. Originally scheduled for complete phase out in April of 1984, it kept getting postponed while NASA awaited TDRSS to come online.[1]

The original plan was to transfer the equipment and tracking responsibilities of the station to the Navy's Pacific Missile Range Facility (PMRF) on nearby Barking Sands. The memorandum of agreement for this transfer had in fact been signed-off by both NASA and the DOD when the *Challenger* accident happened in January 1986. After STS-26, the station was officially closed on 30 September 1989 after TDRS-4 was checked out and declared operational, and the transfer to PMRF took take place at that time. The Navy took possession of most of the equipment with the exception of one key asset which NASA retained, the 9-meter (30-foot) S-band antenna system used by KPGO.

One of KPGO's first assignment in its new Earth observation role was to support Goddard's Crustal Dynamics Project. It joined several other observatories in the continental United States, Japan, Chile, and Australia to make ultra-precise position determination of the crust using the tracking measurement technique called Very Long Baseline Interferometry, or VLBI. Kokee Park participated in these NASA and Naval Observatory sponsored experiments and because of its location in the mid-Pacific tectonic plate, was among the most active of the more than 30 observatories around the world.[2]

In this application of VLBI, several radio telescopes (observatories) simultaneously received signals from extra-galactic quasar radio wave sources. Using lasers and the most precise clocks in the world, the difference in time of arrival of the signals due to the slightly different path lengths from the quasar to each VLBI observatory around the world could be determined to an accuracy of $1x10^{-11}$ seconds (10-trillionth of a second) and their relative positions measured to better than 1 centimeter (0.4 inches).[3] These ultra-precise position measurements, when made repeatedly over several years to decades, allowed scientists to plot the contemporary motion of the tectonic plates—the enormous pieces of Earth's crust—as they moved slowly with respect to each other. The observatories were also able to monitor other geodynamic parameters such as the very complex variation of Earth's spin rate with the minute wobble of the spin axis.

All these gave insight, unavailable before this time, into global geophysics and the underlying forces that led to earthquakes, for example. VLBI measurements which have been made at KPGO since 1984 and which continue today, showed clearly that the Hawaiian Islands (located on the Pacific plate) move at a rate of some 9 centimeters (3.5 inches) a year with respect to the North American plate.

In this new mission, Kokee Park was a principal ground station that diversified to support science application satellites from across several U.S. government agencies. One was the Department of Commerce's PEACESAT (Pan-Pacific Education and Communication Experiments by Satellite) program, which provided medical, educational, and cultural satellite communications between Hawaii and the remote islands in the Pacific basin. It also supported GSFC's Interplanetary Monitoring Platform-8 (IMP-8) that monitored Earth's magnetic field and solar wind activities. In addition, KPGO supported the GOES (Geostationary Observational Environmental Satellite) program for the state of Hawaii.

In South America, the station at Santiago—one of the original Minitrack sites established in 1957 and which had been mostly operated by the Chileans—was completely turned over in 1988 to the University of Chile, who operates it to this day. NASA, though, still has a stake in the station, but now strictly as a customer. Because of its optimal location in the Southern Hemisphere, the United States pays Chile about half a million dollars a year to support a finite number of satellite passes. The number averages out to about two or three passes a day depending on what missions need support. Bill Watson at Headquarters explained how the Agency uses the station today to meet its data pass requirements.

> Some days we take none, some days we take a lot depending on what's going on. Sometimes Santiago is one of a few Southern Hemisphere stations that we have so when something is happening in the Southern Hemisphere and we need coverage, that is a convenient place. Sometimes there are planetary flybys, JPL satellites whizzing by the Earth. They are going so fast near the Earth that their big antennas can't slew fast enough to track, so stations like Santiago will support it.[4]

In effect, a station that the United States in cooperation with the government of Chile started nearly 50 years ago continues in its legacy today.

The surest sign that the era of NASA's world-wide network of spaceflight tracking stations have come and gone was when Bermuda was finally phased out in 1997. Since 1962, when it first gave John Glenn the "go for orbit" call, Bermuda had supported every human spaceflight that NASA had flown, making the critical go/no-go call on all of them—an impressive resume of 118 missions. On 19 November 1997, *Columbia* took to the air on the 88th flight of the Shuttle program. In a Space Shuttle first, the entire stack was rolled from its usual belly-up to a belly-down position in a 40-second Roll-To-Heads-Up (RTHU) maneuver six-minutes after liftoff. Prior to this flight, such a maneuver would have been used only if a Trans-Atlantic Abort emergency landing were declared by Mission Control due to a failed main engine or the loss of cabin pressure during the crew's ascent into orbit.[5]

The RTHU maneuver was added to eliminate the Shuttle's large External Tank from obstructing the communication line-of-sight between the vehicle's antennas and the TDRS-East spacecraft. By doing so, a smooth handover from Merritt Island to TDRSS could be made with only a momentary gap in coverage. Up until that mission, the Shuttle switched over to the space-based tracking satellites only after reaching orbit some eight and a half minutes after launch. The RTHU maneuver—used ever since on all low inclination, easterly launches—allowed the Orbiter to communicate with TDRS about two and a half minutes sooner. (Higher inclination launches towards the northeast for flights to the ISS did not have to perform the roll maneuver due to the availability of DOD tracking stations along the East Coast.) Although tricky, the roll maneuver did not unduly stress the vehicle since it was done well after the SRBs had jettisoned and the Shuttle itself had passed through the thickest part of the atmosphere so that aerodynamic stresses were not a problem.[6]

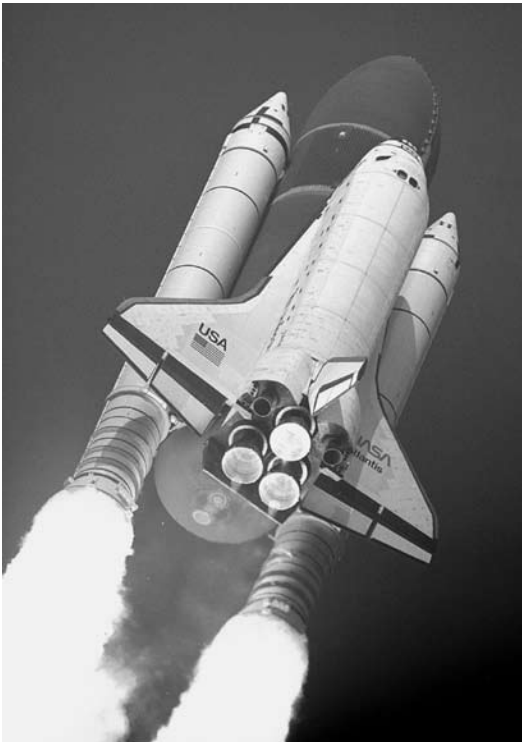
Bermuda was needed no more. Ultimately though, the decision to close the site came down to cost. The closing saved NASA $5 million a year, which coincidently, was the same amount it cost to build the station in 1961.[7]

With Bermuda closed, Merritt Island/Ponce de Leon (MILA/PDL) became the only source of tracking data for the first seven minutes of each Space Shuttle launch. Despite the phase out of all the original ground stations in the STDN, MILA still remains. In fact, it is as essential today after over 100 Space Shuttle launches as it was for STS-1 back in 1981.

Located adjacent to Launch Complex 39 at the KSC, MILA (acronym for "Merritt Island Launch Annex to Cape Canaveral," the early name of the area that was eventually renamed the John F. Kennedy Space Center) was greatly expanded in 1972 right after Apollo 17. The site was used to get Shuttle data to the Launch Control Center at Kennedy during prelaunch testing and terminal countdown. Once the vehicle cleared the tower, MILA transmitted data to Mission Control in Houston. The GSFC first established MILA in 1966 as a primary MSFN station to provide Earth orbit support for Apollo. The station received the first television signals using Unified S-Band during the Apollo Saturn 203 mission on 5 July 1966 on a flight first testing the performance of the liquid hydrogen fuel in the S-IVB third stage to verify its on-orbit restart capability.

Shortly thereafter, GSFC worked with JSC and equipped the station with a complete set of flight control consoles in order to train Mission Control engineers during prelaunch testing of the CSM and LM. The consoles were used until the end of the program in December 1972. In the mid-1970s when S-band transmitters were added to NASA's Delta and Atlas-Centaur expendable launch vehicles, MILA became really busy, supporting those programs as well as Skylab and Apollo-Soyuz. When the STADAN station at Fort Myers was shut down in 1972, its VHF telemetry and communication equipment were relocated to MILA, greatly enhancing the station's capability to also support application satellites programs.[8] With 13 antennas, including a 9-meter (30-foot) USB system, C-band radar, full TT&C capabilities and a UHF air-to-ground voice link for backup, MILA was (and is) NASA's primary launch area tracking station.[9]

As development of the large SRBs of the Space Shuttle neared completion in the mid to late 1970s, GSFC, working with the MSFC, predicted a potential "plume attenuation" problem in which the high temperature, highly reflective plasma in the rockets' exhaust interfered with MILA's reception of signals from the Shuttle early in its ascent. The phenomenon would have been something akin to trying to follow the flight of a bird with a pair of binoculars while looking through a cloud. To solve this problem, a site with a different



Prior to STS-87, Shuttle flights on easterly trajectories went all the way into orbit on their backs. The Shuttle now performs a Roll-to-Heads-Up (RTHU) maneuver prior to main engine cutoff so that communication with TDRSS can be established some two and a half minutes sooner. This allowed the Bermuda Station to be closed down in 1997. (NASA Image Number GPN-2000-000736)

look-angle had to be found. What followed was the Ponce de Leon Station (PDL) "wing-site" that was set up in 1979. Located 64 kilometers (40 miles) north of MILA on 1.4 acres of U.S. Coast Guard property, it was just south of the Ponce de Leon Inlet at New Smyrna Beach. PDL provided a different viewing angle, putting it outside of the "plume shadow." A 4.3-meter (14-foot) USB system was setup specifically to circumvent this problem.

Upon loss-of-signal at MILA, PDL took over as the primary station during a launch, communicating with the Shuttle during its second minute of flight. PDL, however, could not directly communicate with Mission Control at the JSC; MILA still had to do this. Therefore, a three-hop, microwave system with towers at Shiloh and North Wilson were built to relay data from the wing-site to the main location (again, not unlike relaying of cell phone calls). Strictly a supplement to Merritt Island, Ponce de Leon was normally not even staffed, with two or three technicians dispatched to the station to support flight readiness, countdown activities and the actual launch.[10]

With PDL tagged to cover this 60-second gap, according to Shuttle flight rules, a backup to the site itself had to be identified. This dual-redundant requirement harbored back to the early days of NASA human flight operations where a back up was required for any system designated as primary. To this end, a search was conducted in the southern Florida area to find a location suitable to back up Ponce de Leon. Communication link analysis showed that the Air Force's Jonathan Dickinson Missile Tracking Annex (JDMTA) some 150 kilometers (95 miles) south of the Cape near Jupiter, Florida, could back up PDL for S-band downlink. The DOD had constructed this facility in 1985 and 1986 on 11 acres of land in the state park to provide launch support for their launches and missile testing activities. This allowed the Air Force to permanently shut down its more expensive Grand Bahama tracking station. (The latter had provided launch support for over three decades, from 1954 to 1987, first for the Air Force and then for NASA.) Jonathan Dickinson already had everything that Goddard engineers were looking for, including radar, telemetry, a microwave relay to the Cape, and a command destruct system that could be remotely activated from the Cape if it were ever necessary to protect life and property should a launch go awry.

Since MILA was so crucial, the site continually evolved and was upgraded. The most dramatic change was its transition from a mostly human-operated site to autonomous operation, which has, not surprisingly, significantly reduced costs. While not a switchover to purely unattended (or "lights-out") operations, the change brought on by the ever increasing reliance on automation and computer processing has been beneficial, significantly reducing the station's staffing requirements. During the height of Apollo and for STS-1, for instance, the station employed upwards of 140 workers. That number has dropped dramatically to where less than 40 people are now required.[11]

Even as staffing was being reduced, modernization of technology increased. In 1995, the station went to an "all fiber" system, with fiber optics replacing all the communication lines between MILA, PDL and the control facilities at the KSC. A year later, a UHF voice system with a powerful, state-of-the-art quad-helix antenna was installed to support the Shuttle in the event of a Return to Launch Site (RTLS) abort. Today, Merritt Island has become a full-service spaceport communications facility, boasting a suite of 15 antennas that support all phases of a Shuttle flight—from prelaunch checkout to launch, on-orbit (via TDRSS) and landing. Leveraging each other's assets has enabled the DOD and NASA (and more recently the commercial launch industry) to support a wide range of space launches from Florida. As former Station Director Tony Ippolito put it, "All of this has allowed us a more business oriented approach in the operation of MILA."[12]

With near-Earth space communications now well covered by the TDRSS and the SN (with the Jet Propulsion Laboratory's DSN handling planetary work), the emphasis for NASA to support suborbital science missions has, in turn, made Goddard's Wallops Flight Facility home to the GN's most

Merritt Island, MILA (top) and Ponce de Leon, PDL (bottom) provided uninterrupted launch vehicle tracking out of the Kennedy Space Center (KSC). Shown are the MILA operations building along with the station's two 9-meter (30-foot) Unified S-band (USB) antennas used for tracking, telemetry, command (TT&C), and voice. The less complex PDL "wing station" had a 4.3-meter (14.1-foot) antenna used to cover loss-of-signal at MILA from the exhaust of the Shuttle's Solid Rocket Boosters (SRB). (Un-numbered Kennedy Space Center images, *science.ksc.nasa.gov/facilities/mila/milstor.html*, *science.ksc.nasa.gov/facilities/mila/pdl.html*, accessed 21 November 2005)) extensively equipped facility. Located on Wallops Island off the Delmarva Peninsula coast of Virginia, Wallops is NASA's lead facility for implementing its suborbital and special low-orbit research projects. Established by NACA in 1945, the 6,200-acre facility is today staffed by 1,000 full-time government personnel and contractors who support everything from sounding rocket and balloon launches to conducting unpiloted aerial vehicle research.[13]

The beginnings of Wallops date back to the end of the Second World War. In 1945, NACA authorized the LRC to develop the small off-shore island into an aeronautical range where rocket propelled models can be launched to conduct studies of the upper atmosphere. In this way, Wallops became the oldest civilian launch site in the United States. The facility allowed Langley scientists to have many more options in conducting their research, like overcoming the limited capabilities of the wind tunnels of the day, for example. With the establishment of NASA in 1958, the creation of the "manned-satellite" (Mercury) program and Wallops's close association with Langley and its STG, much of the activities there quickly turned to developing the components needed for putting a human in space. This included designing capsule escape techniques, pressure testing of the early blunt-body aerodynamic designs and flight test support of heat shield development and ocean recovery techniques.[14]

In addition to the emphasis put on Mercury, research in the aviation arena continued. The facility's airport, for instance, was used to develop and test runway surface designs for aircraft noise reduction. And it was at Wallops that the Scout launch vehicle solidified its place in history as the premier rocket for launching small payloads for the scientific community, with a remarkable 100 percent success rate since 1976. It was here that the Scout became the first solid fuel rocket to place a satellite into orbit when, on 16 February 1961, it successfully launched a 44-kilogram (96-pound) NASA atmospheric research payload into orbit.[15]

On 19 October 1981, the Wallops Flight Center, as it was then called, was consolidated under GSFC management and redesignated the Suborbital Projects and Operations Directorate, otherwise known as the Wallops Flight Facility. Less than five years later, in April 1986, the tracking station that was part of the NTTF located on the grounds of GSFC, was transferred to Wallops. The flight facility now had the added responsibility for capturing small satellite telemetry, tracking, and command. Many of the first satellites supported from the facility would go on to become some of NASA's most successful orbital science platforms. Among them were the IUE, the Inter-planetary Monitoring Platform (IMP-7), and the Cosmic Background Explorer (COBE). To better handle the additional workload, the facility soon underwent a one-year modification where existing hardware was supplemented with equipment from former STDN stations around the world that were then being phased out. A new communications system was added as part of the upgrade to transmit data from Wallops to the Project Control Centers located back at Goddard.[16]

In the late 1990's, the facility began developing ways to really expand its sphere of operations so as to more effectively support launches at locations away from Wallops Island and the immediate Virginia coast area. Mission operations at Wallops took on a new dimension when it began operating the Mobile Range Control System, or MRCS. Developed by the Center's Electrical Systems Branch, the MRCS is a self-contained, transportable launch system that can be loaded into a military cargo aircraft such as the C-130 and flown around the world to conduct satellite launches at remote locations as needed. It in fact acts somewhat like a transportable range, equipped with an Uninterruptible Power Supply, a range safety display and redundant command destruct transmitters for flight termination along with all the necessary computers and communication equipment needed to support a launch in a "turnkey" fashion.[17]

Before there was the MRCS, setting up a mobile range was much more cumbersome and logistically demanding, translating into higher cost. Equipment in several vans and trailers had to be transported either by air or by sea and put together upon arrival at the remote location. One former MRCS Project Manager noted the tremendous advantage this new system offered, saying "In comparison with the older collection of subsystems in separate trailers, the fully integrated MRCS can be completely tested prior to shipment. This helps reduce mission support and cost."[18]

True to its calling, the Wallops's mobile range has been well traveled since 1997, supporting launches from the nearby Coquina Outer Banks of North Carolina, to the Canary Islands in the East Atlantic and even as far north as Kodiak Island, Alaska. To support the commercial launch market, the MRCS was granted a license in 1999 by the FAA's Office of the Associate Administrator for Commercial Space Transportation (FAA/AST), which allows private paying customers from the U.S. commercial launch industry to use the system to launch their payload into space.[19]

All these developments have made Wallops Island (also known to the commercial launch sector as the Mid-Atlantic Regional Spaceport) America's preeminent small rocket facility. As a controlled range, it has the authority to clear airspace and reroute planes in times of need. Since Wallops's mission is so diverse, the ground station there is somewhat unique in that it has a combination of some very old antennas alongside state-of-the-art equipment. It still operates, for example, an original VHF antenna for ISS and Russian Soyuz voice support. A VHF Satellite Automatic Tracking Antenna/Satellite Command Antenna on Medium Pedestal—SATAN/SCAMP telemetry/command system—from the 1960s can also be found still operating there. Although rendered obsolete when stations began using microwaves to transmit data over long distances, this old system was kept to support the facility's suborbital and short-range data needs. Also, there are the original

The remote barrier-island location of Wallops Island on Virginia's Eastern Shore makes it ideal for testing aircraft models and launching small rockets. As the space program evolved, it became one of the Agency's mainstays for launching sounding rockets carrying scientific experiments into the upper atmosphere. In the 1980s, however, a proposal emerged to close Wallops as a way of reducing NASA's operating costs. Instead, officials decided to incorporate the facility into the Goddard Space Flight Center (GSFC) as it relied on the facility for satellite launch, tracking and data support. In this way, Wallops Island Station became the Wallops Flight Facility managed under the Suborbital Projects and Operations Directorate at GSFC. (NASA Image Number GPN-2000-001323)

9-meter (30-foot) S-band antennas that tracked Apollo astronauts to the Moon and back. These "antiques" can be found still being used everyday alongside the station's state-of-the-art 11-meter (36-foot) S-/X-band dual-feed antenna. As one NASA manager puts it, "They have practically one of every kind of antenna out there," which, in some ways, makes Wallops the perfect setting as a nostalgic rocket range.[20] It bridges the gap between an old fashioned test range nestled along the Atlantic coast and the modern twenty-first century spaceport.

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Satellites and spacecraft circling Earth today rely on both the SN and the GN in different ways. The GN of today is used primarily to support aeronautical and atmospheric research, range safety, and high inclination (high latitude) orbital communications. It is in this setting that the new era of NASA's communications network is found, the hallmark of which are *technology expansion* and *commercialization*.

First, the rapid expansion—indeed evolution—in digital telecommunications technology over the last quarter-century has made NASA's space communications a truly global amalgamation that connects every corner of the world. This same technological evolution has also greatly improved the ability of today's stations to perform TT&C functions compared to the previous STDN generation. Station autonomy has greatly reduced the requirements for human staffing. The objective is not to eliminate human-in-the-loop but let automation do what can be done in terms of scheduling, redundancy, and self-testing. Advancements in digital signaling and transmission techniques have allowed for the ever increasing demand for higher bandwidths (traffic) and lower bit-error-rates (accuracy) to be accommodated.

The other trait which can be used to describe the Agency's network operations is commercialization. This should not be surprising when one looks at the trend of space communication in which NASA has historically set the precedence but is now heavily influenced by the commercial sector. Just like the demand for better technology is always a driver, as space moves from the realm of government sponsorship to being a commercial commodity with increasing private industry participation, cost reduction,—and more importantly—profit in today's world of real-time global communications is more important than ever. It is these fundamental paradigm shifts that have taken NASA's STDN of the past to where it is today. This shift has enabled NASA in recent years to put ground stations in very remote regions of the globe where it was just simply not feasible a generation ago.

Take Antarctica, for example. The manpower that would have been needed to make a continuously operating ground station cost effective from such a location would have, in the past, been difficult at best. On top of that would have been the technical challenge of how one would get the data received at the station in a timely manner to their users who may be scattered across many continents.

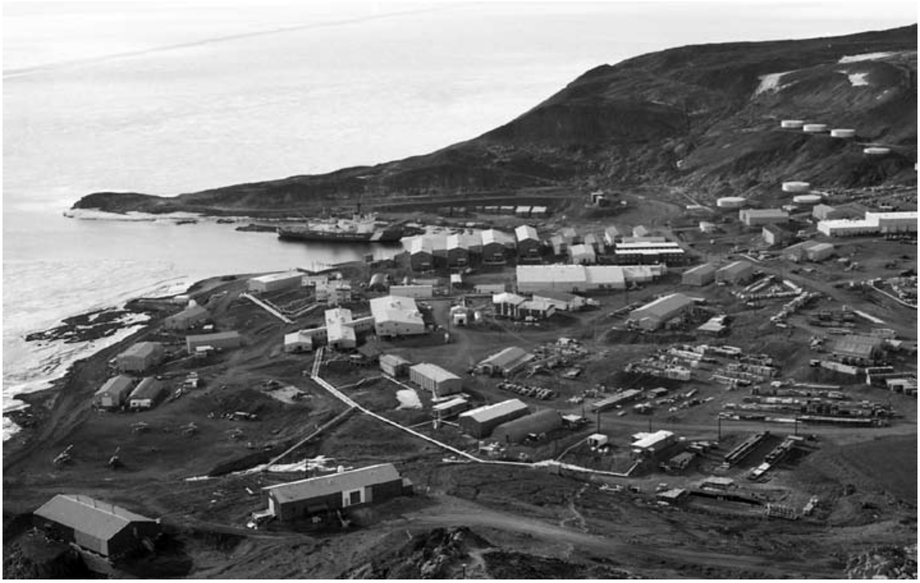
In 1956, the U.S. Navy established McMurdo Station on the continent of Antarctica. At 77° 50' south latitude, McMurdo is well inside the Antarctic Circle and is the southern most harbor in the world. It is also Antarctica's largest community and the continent's center of activity. Built on the bare volcanic rock of Hut Point Peninsula on Ross Island, it is the farthest south solid ground that is accessible by ship. As early as 1901, McMurdo took on some sense of import when it became the staging point for the race to plant the first flag at the South Pole. Among the landmarks still preserved (by the New Zealand government) from that era is Hut Point, left behind by the doomed expedition of British Naval officer Robert F. Scott and his party in 1910. That year, Scott—with his team of four companions—embarked on an expedition with the aim of becoming the first man to reach the South Pole. The 2,964-kilometer (1,842-mile) trip was the longest continuous sled journey ever attempted in the polar regions. On 18 January 1912, they reached the bottom of the world only to find the tent and flag of the Norwegian explorer Roald E. G. Amundsen, who had achieved the goal only five-weeks earlier. Demoralized and short on supplies, Scott and his men never made it back to McMurdo. The return journey ended in the loss of the entire party. Scott came to within 18 kilometers (11 miles) of a supply depot when he and his remaining two teammates perished of starvation and exposure. Their remains, along with diaries left by Scott in his tent, were found by a search party almost eight months later.[21]

Since 1956, McMurdo has grown from an outpost of a few buildings to the largest community on the icy continent with more than 100 structures, an outlying airport (Williams Field) with landing strips on sea ice and shelf ice, and a helicopter pad. Despite its remote location, McMurdo is among the most ethnically diverse communities per capita anywhere to be found. During the summer months, the population can swell to over 1,000 people, attracting scientists, construction workers and polar explorers from all nations around the world. During the harsh winter months of March to October, the population usually drops down to below 250 people who, except for time of emergencies, find themselves pretty much isolated for the winter.

Like a small town, there is a freshwater system, sewer, telephone, and power lines linking the buildings. Science equipment at McMurdo include diving equipment, recompression chambers for diving accident victims, cosmic ray monitors, and facilities to study magnetosphere and ionosphere phenomena. From the runways of Williams Field 16 kilometers (10 miles) away, flights span the continent and to airbases in and out of New Zealand. While skid-equipped planes can fly in and out of the frozen landing strips year-round, it was not until 1992 when a permanent, hard-ice runway on the Ross Ice Shelf was completed that larger transporters equipped with wheeled landing gears could come and go more frequently thereby greatly increasing the availability of supplies to the delight of the personnel stationed there.[22]

It is in this unique part of the world that NASA teamed up with the National Science Foundation (NSF) to establish the southern most satellite data acquisition station in the world.[23] The McMurdo Ground Station (MGS) is today home to a 10-meter (32-foot) S- and X-dual band NASA antenna located atop the 152-meter (500-foot) Arrival Heights peak. From this vantage point, it has a fantastic view in all directions. Looking south, it can see satellites on the other side of the Pole. NASA's original requirement there was to support a joint effort by the two Agencies (along with international partners) to radar map the entire Antarctic continent by satellite.

Operational since 1996, MGS started out collecting X-band telemetry (frequencies in the 5- to 11-gigahertz range in the electromagnetic spectrum, higher than C-band but lower than Ku-band) on about 25 passes each day from ERS-1 and ERS-2, the European Earth Resource Satellites, and the Canadian synthetic aperture radar mapping satellite *RADARSAT*. The



McMurdo, Antarctica is the world's southern-most port and home to numerous expeditions to the South Pole since 1901. The McMurdo Ground Station is located on nearby Arrival Heights Peak. (Photograph courtesy of NASA)

station's S-band capability was put to use not long after in August of 1997 when a NASA Lewis land imaging satellite malfunctioned and began tumbling shortly after launch. Because MGS could see virtually every pass, it was a real asset in the rescue attempt. Unfortunately the spacecraft could not be stabilized and was consumed in a fiery reentry just 36 days after its launch. NASA today uses McMurdo as a data collection hub for satellites monitoring ice movements in the Southern Hemisphere. Such data is used immediately on site by scientists on the continent as well as by those planning re-supply shipping routes in and out of Antarctica.[24]

Despite the fact that few other ground stations have the capability of MGS to collect the enormous volume of data that can only be done at the Poles, communications in and out of the continent is still not so good. The only way to get data out is through something called the McMurdo TDRSS Relay System, or MTRS, which consists of two antennas (4- and 7-meter [13- and 23-foot] dishes) that actually communicate with the TDRSS. NASA uses a nearby microwave tower to relay signals to the MTRS at a place called Black Island located about 50 kilometers (30 miles) closer to the Equator. Due to the curvature of Earth and the way a satellite travels in polar orbit, near the poles, even this relatively short distance can make a big difference to provide a much better view to relay satellites. The drawback for NASA, however, is that since the link is shared with the NSF, it is only used occasionally so as not to overwhelm the NSF's ability to send data off the continent on the always busy TDRSS.

Rounding out Antarctic communications is a small system located right at the South Pole. Although not really part of NASA's GN, it allows polar scientists there to communicate with TDRS-1—the original satellite—on brief occasions when it pops above the horizon while performing its "figure-8" loop in the vicinity of the Equator. These ongoing efforts to build a good communications network on this most desolate of places has only recently culminated, allowing the inhabitants to join that most global of communities: the Internet. This accomplishment is not lost on those who run the space agency's networks. The proclamation "We brought internet to the South Pole!" sums up the Agency's legacy on Antarctica rather nicely.[25]

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Antarctica and the South Pole are not the only places to have been "tamed." In this new era of ground stations, NASA has also been busy on the

A team from the Goddard Space Flight Center (GSFC) visit the Intelsat communications relay station on Black Island in 1999. Note the microwave tower link back to McMurdo. (Photograph courtesy of NASA) other end of the globe. While the mid-latitude location of the continental United States makes for a good setting for launching science payloads into orbit (Wallops, Cape Canaveral), it cannot however, provide routine, low-cost, launch access to investigate interesting activities that permeate the upper atmosphere in the polar regions, activities such as Aurora Borealis, or the northern lights. To do this, one must venture near the Arctic Circle, to a place called Poker Flat some 30 miles north of Fairbanks, Alaska.

Owned and operated by the University of Alaska's Geophysical Institute since 1968, Poker Flat Research Range has been primarily dedicated to the launch of sounding rockets for the purpose of middle to upper atmospheric research. The first rocket was launched there in 1954. The rather enticing name Poker Flat is believed to have been taken from American author and poet F. Bret Harte's rags-to-riches short story, *The Outcasts of Poker Flat*, which in a way describes the inauspicious beginnings of the original ad hoc launch site that was constructed from begged and borrowed materials. But the range could have simply been named after nearby Poker Creek. In any case, Poker Flat is today the only nongovernment, university owned and operated range in the world. It is also the only high-latitude, polar region, rocket launching facility in the United States.

Because of its importance, NASA has funded the operation of the range under a cooperative agreement with the University of Alaska's Geophysical Institute since 1979, assuming funding responsibilities previously held by the National Oceanic and Atmospheric Administration (NOAA). Much bigger than the birthplace of America's missile activities at White Sands, Poker Flat is in fact the world's largest, land-based rocket range. It consists of a chain of downrange flight and observation sites spanning inland Alaska to Spitsbergen in the Arctic Ocean that are used to monitor and help recover payloads. Since it is an active rocket range, NASA and the university have to coordinate their activities with many U.S. government agencies. The FAA must approve and coordinate the air space during launches. Also, since the range is so large, permission to impact rockets and their payload on its 26 million acres of land has to be authorized by a whole host of government agencies, including: the Bureau of Land Management; the U.S. Fish and Wildlife Service; the State of Alaska Division of Lands; Doyon, Ltd. (the largest private landowner in the state of Alaska); and the Village Traditional Councils of Venetie and Arctic Village. Unlike bygone days at the dawn of the Space Age, environmental regulations mandate much of what can go on at these ranges today.[26]

As with the oil pipelines a quarter-century before, Alaska today serves as the great northern frontier. But this time, instead of energy, the commodity is information. More specifically, the information age revolution and commercialization of space. In fact, AGS, the Alaska Ground Station at Poker Flat, is not really even a NASA owned station at all. Rather, it is part of a commercial network of ground stations called DataLynx, which is owned and operated by Honeywell Technology Solutions, Inc. With U.S. and international partners such as Universal Space Network, the Australian CSIRO, and the Japanese Institute for Aerospace Technology (JAXA), just to name a few, DataLynx has today expanded to over 20 ground stations on six continents.

Mirroring in many ways NASA's STDN of the previous generation, DataLynx stations today operate in a latitude band spanning 78° north at Svalbard, Norway, down to 33° south at the Santiago Station operated by the University of Chile. In fact, locations of many of the stations harbor back to the STDN days (and even earlier), with places like Hartebeesthoek, South Africa; Perth, Australia; and as mentioned, Santiago. Other places such as Beijing, China—a location which would have been impossible to imagine during the Cold War—have become part of this new age in commercial networking designed to serve satellite-using customers from around the world. With profit openly the bottom line, DataLynx, which depends highly on automation and "lights-out" operations, advertises itself as a " rapid, proven, reliable, cost effective mission-critical . . . distributed partner network," one that offers 24/7 command, control, and communications for "broad and flexible solutions, reducing cost and risk to our clients so that they can focus their resources on their core businesses."[27]

One of these clients is none other than NASA, the one who subsidizes Poker Flat, the very range that the Alaska Ground Station sits on. With $5 to $6 million a year, the Agency literally buys a minimum number of passes each day using the station's 11-meter (36-foot) antenna. (AGS also supplements this system with a smaller 5-meter (16.4-foot) S-band system called the Low Earth Orbit Terminal as well as a somewhat larger 8-meter (26.24-foot) transportable S-band antenna called the Transportable Orbital Tracking System.) Assuming 36 passes a day, this averages out to approximately $400 per pass, a figure that is much more economical to NASA than what it would cost to otherwise engineer, build, operate, and maintain a station of its own. It is therefore a truly joint government/industry arrangement that in the end benefits both NASA and the DatyLynx stakeholders.

Program Executive Bill Watson explained the arrangement which in a way captures the business-end of how ground stations in the twenty-first century works: "In this case, Honeywell not only owns DataLynx but they also won the current contract for operating the GNs. So they consolidated the deal and said we will treat the government assets and commercial assets as a pooled resource. You give us a guaranteed annual amount of revenue and we will guarantee you a minimum number of passes per day, and then if we [NASA] go over that, we pay by the pass. So it's a quasi-government commercial activity."[28]

While the Alaska station at Poker Flat is located just outside of the Arctic Circle, there is yet another ground station which continues this joint, government-to-private enterprise theme but is situated a mere 965 kilometers (600 miles) from the North Pole itself. It is here on the Norwegian archipelago of Svalbard that the world's northern-most, permanent, satellite ground station can be found at 81° latitude near the top of the world.

The earliest written records documenting the existence of these frozen polar islands date back to the late twelfth century by the Vikings as they sojourned about the Arctic Ocean. For the next 400 years, though, Svalbard—which means "cold edge" or "cold coast"—was largely forgotten. Then in 1596, the islands were accidentally rediscovered by an expedition led by the great Dutch seaman Willem Barents while searching for a Northeast trade passage to Asia. This was followed by the English explorer Henry Hudson, who mapped the area and reported good whaling there. This spurred a bitter quarrel between English and Dutch whalers over the territory. In 1618, a compromise was reached, with the Dutch limiting their operations to the northern part, leaving the rest to the English, the French and the Hanseatic League (an alliance of trading cities that maintained a trade monopoly over northern Europe between the 13th and 17th centuries). The Danes also claimed the archipelagos as part of Greenland.

Over the next 300 years, various countries such as Norway, Russia, and Sweden laid claim to the islands, this especially after coal—the great source of energy that could empower the new steam engines—was discovered there in the late nineteenth century. Norway finally took formal possession of Svalbard in 1925 after a treaty was signed in Paris after the First World War. (Russia, who did not sign the accords, was to dispute Norway's stance on the islands well into the latter part of the century.) The islands again came to the forefront when, during the Second World War, it was the scene of some very intense naval battles between Germany and the Allies due to its rich deposit of coal.

Although Svalbard's claim to fame for years had been its geographical setting serving as the staging point for North Pole explorers, it was not until 1990 that Norway officially opened up the region to general tourism, greatly expanding its economic base and spurring on the development of new industries. In 1997, the Norwegian Space Center (NSC), along with the private space conglomerate Konnesberg Satellite Services (KSAT), began putting together the Svalbard Satellite Ground Station at Platåberget, near the town of Longyearbyen. SvalSat, or SGS, is today a truly general purpose facility, providing customers with tracking, telemetry, and data returns from a host of polar orbiting satellites.[29]

While NASA knew that the Alaska Ground Station was in a fairly good location at 65° latitude, it could, nevertheless, only observe about 14 out of every 16 passes that were actually available each 24 hours. With SGS being less than 1,000 kilometers from the North Pole, it could literally see every single polar orbit pass. Therefore, when Norway approached NASA to join their operations, it was a rather easy decision. The Agency first put up a trailer (often covered by a tent to keep the snow off) and an antenna in 1997. The site has steadily grown since then into sort of a "space park" of the Arctic. NASA now

With its extreme northern location on the Svalbard archipelago (78°13' latitude), SGS is the only ground station in the world able to provide all-orbit support of polar orbiting satellites. Six multi-mission antenna systems, along with several minor antenna systems, are used for TT&C and operations. One of the systems is dedicated to the NASA Ground Network (in shared operations with EUMETSAT) and is operated locally by SvalSat. The remaining antennas are remotely controlled and operated from Tromsø at the Tromsø Network Operations Center 1,000 kilometers (600 miles) to the south on the Norwegian mainland. (KSAT photograph, *https://www.spacecommunications.nasa.gov/spacecomm*, accessed 22 August 2007)

operates an 11-meter (36-foot) S/X-band antenna there. Here, the Americans join the Norwegian Space Center and Kongsberg, as well as EUMETSAT (the European Organization for the Exploitation of Meteorological Satellites), to make up the world's northern-most tracking station.

Surrounded by "the King of the Arctic" polar bears—personnel are required to carry a weapon when working outside—the space park continues to grow. One of its hallmarks is the ability to get large amounts of data quickly off the island with the use of fiber optics. NASA arranged in 2004 to have the NSC install redundant fiber optics all the way back to the United States, much to the delight of data users on the North American continent. With this capability, NASA's communications to Norway today are actually much more robust than those to Alaska. Taking the Agency's domestic, government-industry relationship in Alaska to an international level, the operation in Svalbard serves as a model for the way space is being treated openly as an international commercial commodity.

Unlike days bygone, the United States and the (former) Soviet Union are by no means the only torch bearers. Watson explained:

> The Norwegians made us a deal. They said you're [NASA] paying $6 million *a year* now for commercial relay satellite services to haul data out of Norway. For $5 million for *five years*, we will install the fiber and then give you the next *15 years* for free. How could we turn that deal down! And what they did was they made a similar offer to NOAA and so between NASA and NOAA, they got a revenue stream of about $10 million a year. They went off to a commercial financier and got the money, . . . basically borrowed it against a promissory. The implication was that NASA and NOAA would commit to pay for five-years. . . . They brought two ships in and laid redundant fiber, two different paths so if one gets cut, we still have the other. It was a remarkable plan.[30]

Svalbard has proven to be a win-win situation for both NASA and the Norwegians. What began as a joint venture to gather a few more satellite passes has basically turned this faraway mining town into what is one of the best wired and well connected places anywhere in the world. In a way, NASA's operations at Svalbard bring the GN of the twenty-first century full circle to how it all began nearly half a century ago. Back then, the emphasis was on hiring local people and training them to "nationalize the station." This worked well at many places, from Chile to Ecuador to Guam. With Norway, this is very much a continuation of that legacy, except NASA no longer has to provide all the technology and set all the precedence. At Svalbard, the Norwegians did not need that "leg up" to turn their concept into a reality.

In a sense, while America was winning the space race, the rest of the world caught up.

★ ★ ★

Throughout the 1990s, the phrase "Faster, Better, Cheaper" became somewhat of a choreographed aphorism that drove much of the way business was conducted in the high technology world, both in the private sector and in the government. This approach impacted the space program in ways ranging from economics to performance and, some would argue, safety. For critics, "Faster, Better, Cheaper" was usually followed by "Two out of three aren't bad!"

In this era of commercialization, the approach as to how ground stations were to be built and how they were to be used began to change. "Lights out" operations and station autonomy entered the scene. Companies like USN and DataLynx entered the playing field. These multimission network terminals offered users the advantage of low cost services based on the philosophy of "pay only for what you use." Like Santiago, they provided services on a retainer basis with added "per-pass" cost on actual usage, targeting not only commercial users of satellite services but also government users like NASA.

It was in this renewed atmosphere of cost awareness and infrastructure reduction that NASA tried implementing an across-the-board streamlining of its organizations. This included, in particular, its tracking and space communications operations. The goal was actually rather sweeping but straight to the point: back the government out of day-to-day operations. To do this, all management of space operations was consolidated under a single office at the JSC in Houston. The office was named the Space Operations Management Office. Known as SOMO, the name would seemingly take on a life of its own in the coming years, the mere mention of which, even today, conjures up strong feelings on the part of those who were involved.

The decision to establish SOMO was prompted by an Agency-wide examination of space operations requirements as part of a so-called Zero Base Review, completed in 1995. In this review, representatives from NASA Field Centers evaluated opportunities for consolidation, privatization, and commercialization of existing government functions across NASA. The review team recommended several initiatives to achieve cost savings while ensuring a continued, high quality of operations services. It was decided that a single but consolidated, management structure could be implemented that would best accommodate these goals. SOMO would be that management organization. Theoretically, it could be a centralized office that could quickly respond to service requirements as identified by specific NASA programs and projects, and even to external (non-Agency) customer requests for similar services—as long as NASA operations were not interfered with. Whether this was a good idea or not, at least on paper it seemed like it could work.[31]

Under Administrator Daniel S. Goldin's direction, the SOMO was established the following year. Its central objective was to ensure that existing NASA assets were used as efficiently as possible and that duplication was avoided. This objective unavoidably resulted in shuffling of responsibilities (and power) between various organizations within NASA. Not only that, it would also go one step farther by *eliminating* certain offices.[32]

SOMO was purposely designed to be small, with key positions held by about three-dozen individuals from NASA Field Centers who, for all intents and purposes, made the decisions in carrying out all the Agency's space operations. Specifically, the Data Services Manager was from the JPL; the Missions Services Manager was from Goddard; and the Commercialization and NISN Manager was represented by the MSFC.[33]

Thus from JSC, the office soon ended up basically managing all of NASA's space operations, including its vital communication networks and tracking systems. The TDRSS Space Network became a part of it as well as the GN, the NISN and JPL's DSN. In other words, management of the networks suddenly—and for those involved, unbelievably—now came under the auspices of the JSC. This gave JSC an inordinate amount of power. While the move did not take away the GSFC's day-to-day responsibility of operating the network (nor JPL for its Deep Space activities), it did significantly erode the role that Headquarters had in Washington. The Office of Space Communications (OSC, organizational designation "Code O") responded unreservedly to the sweeping mandate to, in effect, do more with less. Staffing at OSC was first reduced by 35 percent, then by 60 percent, and finally, 85 percent. This included elimination of 16 senior level GS-15 and higher positions. With its role greatly reduced, the job of Headquarters was relegated to conducting external interface, determining program requirements and strategic planning.[34] In short, Code O was one of those, which for all intents and purposes, eliminated. The numbers back this up. Prior to consolidation, Code O had in excess of 50 people at Headquarters working the Agency's tracking and communications needs. After the reorganization, scarcely eight remained.[35]

To put it bluntly, space communications—at Headquarters as well as Goddard—was being gutted.

The idea of consolidation was radical but seemed noble enough at the time. NASA established the SOMO (Code M) to oversee its space operations activities and to implement a single Consolidated Space Operations Contract (CSOC) as the initial step to reduce the cost of operations. In this "integrated operations architecture", many of the trends which were permeating space communications in general—trends such as the aforementioned automation and privatization—could take effect. The thinking was that a single, large contract would naturally be more efficient than a plethora of smaller ones. On 25 September 1998, NASA awarded the enormous $3.4 billion operations contract—five year base with an option for an additional five years—to a team led by Lockheed Martin. It was one of the most valuable outsourcing programs ever undertaken by a civilian agency. Under CSOC, five contracts which had up until then operated independently were consolidated on the first day that the contract took effect. (Ten more separate contracts transitioned to CSOC from 1999 to 2004.)[36]

Even NASA was fully aware, however, that the envisioned cost reduction could not take place overnight. While some reduction could be gained initially, the contractor work force supporting space operations at five NASA Centers would have to be reduced gradually over the 10-year period at a rate of slightly less than 100 jobs per year on the average. The idea was that, by implementing the reductions over a decade, essentially all of the attrition could be absorbed through planned retirement, personal job changes and reassignment of contractor employees to other programs.

Even as CSOC was being awarded to industry in 1998, SOMO began exploring several additional commercialization initiatives with the aim of realizing some further, longer term cost savings. For example, services with USN were established. Another component was to provide, using the CSOC contract-vehicle with private industry, opportunities to offset some of NASA's operating cost by marketing unused capacity on the TDRSS. One such initiative—originally conceived by Code O—was to provide "TDRSS time" to commercial oil exploration vessels at sea, as there was virtually no commercially available communication satellite that could support the transfer of the large amounts of data for such application. Through these and other initiatives, SOMO at the JSC projected that a $1.4 billion cost saving could potentially be realized over the next 10 years.[37]

As optimistic as JSC was on the outside, however, it could simply not shed a barrier that soon (and clearly) manifested itself as a growing cancer in the whole SOMO idea. When the office was formed in 1996, program responsibilities moved from Washington to Houston. This had huge repercussions. While the various Field Centers still had their programs to work, this shift in responsibility to Houston naturally did not sit well with them. According to Robert Spearing, who witnessed the whole thing and was one of those actually recruited back from private industry by NASA to help fix the problem, it was putting in charge "an organization that they [the Field Centers] felt was ill-equipped to deal with their issues." Said Spearing,

> What was not understood well was what happens to the work that has to go on at Headquarters is very difficult for a Field Center to perform because they don't have the skills for that. A lot of our work here at Headquarters relates to working with the other agencies of the federal government, both civilian and military, and also working with the Congress to advocate our programs. So you ended up having a very limited capability to perform that function here at Headquarters.[38]

Essentially, SOMO had grossly underestimated the importance of having a team in Washington to take care of business with the rest of the federal government (and international partners). Said Spearing:

> You have to have the right talent here in town for our relationships internationally. . . . When you work with international organizations like the European Space Agency or the Italian Space Agency or the Japanese Space Agencies, all of these organizations look to NASA Headquarters. When someone from a Field Center goes and represents NASA to these organizations, they see that as somewhat of a mismatch. So there were some lessons learned.[39]

By 1998, just two years after SOMO was set up, it was already clear to most that in the process of trying to work issues between the JSC, Headquarters, and the other Field Centers like Goddard, Marshall, and JPL, that it just was not working. Space Communications had been relegated to an office under Code M. There were open and often ugly struggles over who was

NASA's management of its tracking and space communications activities began at Headquarters with the establishment of the Office of Tracking and Data Acquisition (OTDA) on 1 November 1961. This photograph shows its staff in the early 1980s. OTDA was reorganized into the Office of Space Tracking and Data Acquisition (OSTDA) in 1983 and then into the Office of Space Operations (OSO) in 1987. It became the Office of Space Communications (OSC) in 1992. Edmond C. Buckley was OTDA's first Associate Administrator (1961–1968). He was succeeded in that position by Gerald M. Truszynski (1968–1978), William C. Schneider (1978–1980), Robert E. Smylie (1980–1983), Robert O. Aller (1983–1989), Charles T. Force (1989–1996), Wilson T. Lundy (interim Deputy AA 1996), David W. Harris (interim Deputy AA 1997–1998), Robert E. Spearing (1998–present). (Photograph courtesy of Charles Force)

in charge and who had control. Beset by quagmire, something had to be done. The SOMO in Houston eventually came around to this realization. A rather laborious process followed in which the OSC was slowly restored. First, the position of Deputy Associate Administrator for Space Communications under Code M was abolished. It was then placed under the Office of the Deputy Associate Administrator for the Space Shuttle. Later in the year, it was again transferred, this time under the Director for Resources Management. By 2001, Stan C. Newberry, who by then was heading up the SOMO, was holding talks about the future of the office with top agency officials at Headquarters. Not soon thereafter, and with little fanfare, Administrator Dan Goldin dissolved the controversial office and restored program management of space operations back to Washington where they remain today. With the restoration of Code O, management for tracking, data acquisition, and space communications at NASA were reconsolidated. Ten years after the controversial reorganization began, the OSC was finally restored to the structure Buckley had setup 45 years earlier.

In April 2004, at the end of the five-year base period, the CSOC industry contract to the Lockheed-Martin team was terminated and not exercised into the option period.[40] OSC at Headquarters not only survived the SOMO fiasco, it broke apart CSOC. The separate set of five contracts (now collectively called Space Mission Communications and Data Services) divided CSOC's functions fairly equally across three NASA centers—Goddard, Kennedy, and Marshall. The new contracts were collectively worth about $400 million a year, roughly equal to the annual average of the old CSOC. But now Headquarters intended to award, manage and determine the specifics of each contract separately.[41]

Regarding the whole affair, James Costrell of the OSC said, "It was a new concept to NASA. The theory was that spacecom (space communications) is spacecom, that it's all the same. So NASA charged ahead with the idea that a consolidated contract would result in efficiencies."[42]

Of course, it didn't quite work out that way. With the contract managed by SOMO from Houston, other Field Centers found that Lockheed-Martin and its subcontractors could not respond to their needs very effectively. The contract had other weaknesses too. Among the worst was that NASA had to renegotiate prices with the contractors whenever conditions changed. For instance, if the Agency ended a mission, closed a tracking station or took any action that altered the work needed from the industry team, Agency and company managers had to agree on cost revisions. Through the lessons of SOMO and consolidation, NASA learned (the hard way) that one size does not always fit; divide and conquer sometimes works better. "What the agency finally came to grips with was that there are some fundamental differences between the various communications activities," Costrell said.[43]

Although the controversy and subsequent fallout of what is now simply referred to as "consolidation" inside NASA may have in many ways been a failed experiment and a bitter pill to swallow (many were reassigned from GSFC and Headquarters or left the Agency), the ensuing years have shown the resiliency of America's space agency as an organization to overcome and move forward from its setbacks.[44] The revolutionary, new kind of network ushered in by TDRSS and the new mission of today's network of ground stations have helped set the stage for the coming decade. On 14 January 2004, President George W. Bush announced his "New Vision for Space Exploration" to return astronauts to the Moon by the year 2020, to be followed by mankind's first journeys to a neighboring planet.

Space communications have indeed come a long way since engineers first tried to keep track on a little sphere called Sputnik as it beeped its way around the globe. Today, that same technology—which allowed the world to watch live broadcasts of the 1964 Tokyo Games to the "space handshake" of Apollo-Soyuz and webcasting of telemedicine from Antarctica—continues to provide people around the world with sharing of everyday technologies not possible before. Such is the diversity that has allowed live communications from virtually anywhere in the world. Families who have not seen each other in years can stay in touch using cellular telephone networks and video networking on their personal computers. Brilliant HDTV via satellite can be enjoyed, for example, by the outdoorsman on a camping excursion hundreds of kilometers from the nearest city.

As NASA prepares to send humans back to the Moon and launch evermore ambitious space missions into Earth orbit and beyond, the tracking and communications network which Jack Mengel, Ozzie Covington, Ed Buckley and so many others began not so long ago will be there to meet the challenge.

CHAPTER 9

A LEGACY

NASA's STDN supported every U.S. space mission since 1958. Its desire was to stay inconspicuous, the more invisible the better. Much like an offensive lineman in the game of football or a player in an orchestra, they did not want their name called because it usually meant there was a penalty or a wrong note. Yet, the team could not win without the lineman nor could the orchestra music make without every member playing the right note.

How will space communications progress in the decades ahead and how will it best be able to build on the accomplishments of the past?

This is the question the NASA finds itself asking at the dawn of the twenty-first century. But this is not new.

> Man has made remarkable strides in penetrating the atmosphere surrounding his planet and even venturing into space. Scores of objects have been launched into space, many to roam the solar system forever. We stand now on the threshold of a new era of discovery.[1]

This was not the reflection of a modern day philosopher, but rather, something that Ed Buckley said in 1966 even before man had first left the confines of Earth. Bill Wood echoed this sentiment when he was asked in 1983 even before the first TDRS was launched just what the future holds for spaceflight tracking and communications.

> Today, the problems are hardly any different: how to handle reliably and economically a data flow now grown to 50 million bits-per-second and how to make the best use of these data in our search for new knowledge for the benefit of all mankind. We may have new and more advanced technology, but the challenge remains. . . . Our motto was a rather basic one: 'Close is good enough when you are playing horseshoes, but that is not good enough for manned spaceflight!'[2]

The challenge remains. Instead of megabytes (millions of bytes of digital data), today space communications work in gigabytes and terabytes (billions of bytes and higher). Just like it took the pioneers of aviation nearly half a century to go from 10 miles per hour to the speed of sound, the last 50 years of the twentieth century have seen tracking and space communications go from the picket line of Minitrack to the near-instantaneous, on-demand services offered by an invisible network that sees an entire hemisphere of Earth from 36,000 kilometers away.

In an age when global weather forecasts, spectacular images of celestial objects never before seen from space, and live images of astronauts living and working in space are taken for granted, it is difficult to imagine a time when America was struggling to put satellites into space. Engineers were not even sure whether or not they could be reliably tracked let alone prove useful on an everyday basis. From optical and radar tracking to radio interferometry, and from the large, automatic tracking antennas of the 1960s to the SN of today, advancement in communications technology has undergone many evolutions during this time. In fact, entirely new industries have been spawned. Though it may sound a bit trite, the continuing legacy of the spaceflight networks through its many incarnations has not only produced America's success in space but has, in its own way, contributed to such spin-offs as calculators, personal computers, digital watches, cellular telephones, and internet links to remote corners of the world. From VHF and UHF to S-band and Ka-band, the exploitation of higher and higher frequencies across the radio spectrum has enabled the spaceflight networks to meet and plan for the ever-increasing demand for higher bandwidths that are needed both today and for visions on the horizon.

But more than the technology itself, the history of America's STDN is a testament to the people behind the scenes who made it work, both as an organization and as a technological marvel. Leading the way has been the organization at NASA's GSFC, the Agency's focal point for all near-Earth communications and scientific satellite work, a role which it continues to enjoy today. Henry Clements, who was the first Network Controller during Project Mercury, reflected on the role of this Center.

> As for the support provided by the Goddard tracking and communications team, it was outstanding—though it has been largely unrecognized even within NASA's own family. Management, outside the JSC, all too often failed to recognize the very important contributions made by these men and women, engineers and computer experts who were stationed around the world. We could not have done it without them. They got the data to us.[3]

Vern Stelter, who ran the Center's Communications Division from 1962 to 1973, summarized what he and his people were all about. "We were there, but determined to be invisible. Ours was a service on which the programs could depend. We were there when needed."[4]

This unpretentious mindset that the spaceflight tracking network be an "invisible network"—or as former Associate Administrator Charles Force put it like a light switch, always there when you turn it on—was something that Ozzie Covington always stood by. Said Covington unpretentiously years ago:

> I must confess, I had never been able to actually pinpoint what my contributions were. Granted, we pushed the state of the art in the areas of tracking, communications, and computer applications. Maybe it was the assembling of a first rate team of men and women—both in NASA and private industry—who in fact deserve the credit. We were only in the background, providing the links between the astronauts and the Earth.[5]

This first rate team was in fact a testimony to what can be accomplished when industry and the government develop a high level of trust. From Bendix field technicians like Gary Schulz to Senior Managers like Glenn Smith and Cliff Benson or Program Manager Larry Jochen, working the networks became a way of life. Like the early days of Mercury when the Agency had "Go Fever", many had "Island Fever". Some ended up spending their entire careers with the contractor teams, hopping from one locale to another. Some brought their families, others found new ones. As one former supervisor put it, "We didn't make a lot of money, but we had a lot of fun!"[6]

Murray Weingarten, President and Chairman of the Board for Bendix from 1973 to 1989 and who was perhaps the one most influential in establishing this esprit de corps of contractors, once summarized this legacy:

> During the peak of the U.S. space program, some 2,300 Bendix people were committed to this effort. It was a good marriage, based on professional relationships and a dedication that would be difficult for some to understand. It was a productive partnership for both the government and private industry. There is no doubt that it has been effective, and we take great pride that the Congress of the United States referred to these people—both government and industry—as the 'unsung heroes of the space program.'[7]

Author Alfred Rosenthal in 1982 interviewed Gerald M. Truszynski, NASA's top official for Tracking and Data Acquisition from 1968 to 1978, and asked him to describe how the Agency (in particular, the importance of Headquarters charting the course and delegating the responsibilities to the Field Centers) and its contractors were able to meet the unique challenges of the time. The fabric of Truszynski's remark is as true today as when he first spoke compellingly of it 25 years ago:

> One of the major reasons for the outstanding success of the NASA tracking and data acquisition networks lies in the organizational and management approach taken by NASA in this vital area of flight program support. While the variety of these programs was quite broad—ranging from research sounding rockets through scientific satellites, manned missions of great complexity and far ranging planetary missions—all needed the very necessary common denominator of reliable, and in most cases, worldwide tracking and data acquisition support for their accomplishment.
>
> In the beginning days of the space program, there was a tendency to look upon tracking and data support as an associated part of major flight program functions, or as a necessary part of launch vehicle operations. However, early in the 1960s, we were successful in making the point to NASA management that there was a need to organize the tracking and data acquisition and communications function as a single, centralized entity, responsible for the development, implementation and operation of these facilities for support of all of NASA's flight programs. This resulted in a highly efficient structure and gave us the necessary resident technical expertise—in one office—to plan, develop, budget and defend before Congress the requirements for this key activity in an integrated fashion.
>
> The office was able to become an integral part of the overall program planning function at NASA Headquarters and was involved, early on, in the evolution of every major program and thus able to translate mission requirements into network requirements in a timely manner. We now could plan our own destiny. We

were given control over our own financial resources along with the technical expertise in the NASA Field Centers—primarily the Goddard Space Flight Center and the Jet Propulsion Laboratory—where major elements of these centers were directly associated with the tracking and data acquisition function.

The dedication of the people at these Centers was a major factor in the success of our program, and deserving of particular mention. We involved them directly in our planning and, with the splendid cooperation of the Center Directors, had the ability to deal quite directly with the appropriate technical groups to handle our problems with a minimum of administrative delay. Over the years, we evolved a network capability which was extremely reliable by requiring that systems committed for implementation into the network were within the state of the art and had the necessary developmental and test lead times to assure their operational integrity. This, despite the fact that we were working under too stringent, fixed time constraints. Because of this record, we were able to earn the confidence of the flight programs, the support of our management, and the Congress, which gave us the financial resources to get the job done.

Another important element in the success of our operations was the good international cooperation we enjoyed where we were required to establish tracking stations in foreign countries. We, at the outset, always approached each country involved as partners, never attempting to or even suggesting that we establish 'Little Americas.' We encouraged the active participation of the host country in the planning, construction, and subsequent operation of the tracking stations. As a result, we were never refused permission to establish our facilities. Zanzibar [and Havana] was the only facility we had to vacate on short notice when a coup toppled the government.

In the final analysis, the success of any activity usually can be traced to the individual efforts of the personnel who were highly skilled and dedicated in their efforts to provide the highest quality and roost reliable support possible to the space flight programs. The late Congressman Olin Teague referred to these individuals as 'the unsung heroes of the space program.' I certainly share his sentiments and thank each one for a job well done.[8]

As the space agency builds on these accomplishments moving into the future, some challenges remain the same. But some are quite different. Take the ISS and the Space Shuttle—which NASA plans to retire in 2010 after completion of the ISS. To support a Shuttle launch, it is not just the Agency's Space and Ground Networks that are involved. It is a collaborative effort

Official crew portrait of STS-107 which broke apart during reentry on 1 February 2003. From left to right are David M. Brown, Rick D. Husband, Laurel Clark, Kalpana Chawla, Michael P. Anderson, William C. McCool, Ilan Ramon. (NASA Image Number KSC-01PP-1639)

between NASA and the DOD, with international partners also having a stake. In a sense, NASA integrates a network from different organizations in order to meet a particular mission need. And when that mission is over, the network is broken up to allow the different stakeholders to return to their primary functions. This kind of "virtual network" allows the Agency the flexibility it needs to accommodate many different types of missions.

A case in point is the new communications requirement stipulated for the Space Shuttle after *Columbia* broke apart on reentry during the final minutes of STS-107 on 1 February 2003. Foam and ice debris from the Shuttle's giant External Tank during launch punched a hole in the leading edge of the left wing which led to thermal protection breakdown in the 1,650°C (3,000°F) searing heat of reentry, killing the crew of seven. (The crew members on that fateful day were Commander Rick D. Husband; Pilot William C. McCool; Mission Specialists Kalpana Chawla, David M. Brown and Laurel Clark; Payload Commander Michael P. Anderson; and Payload Specialist Ilan Ramon of the Israeli Air Force.)

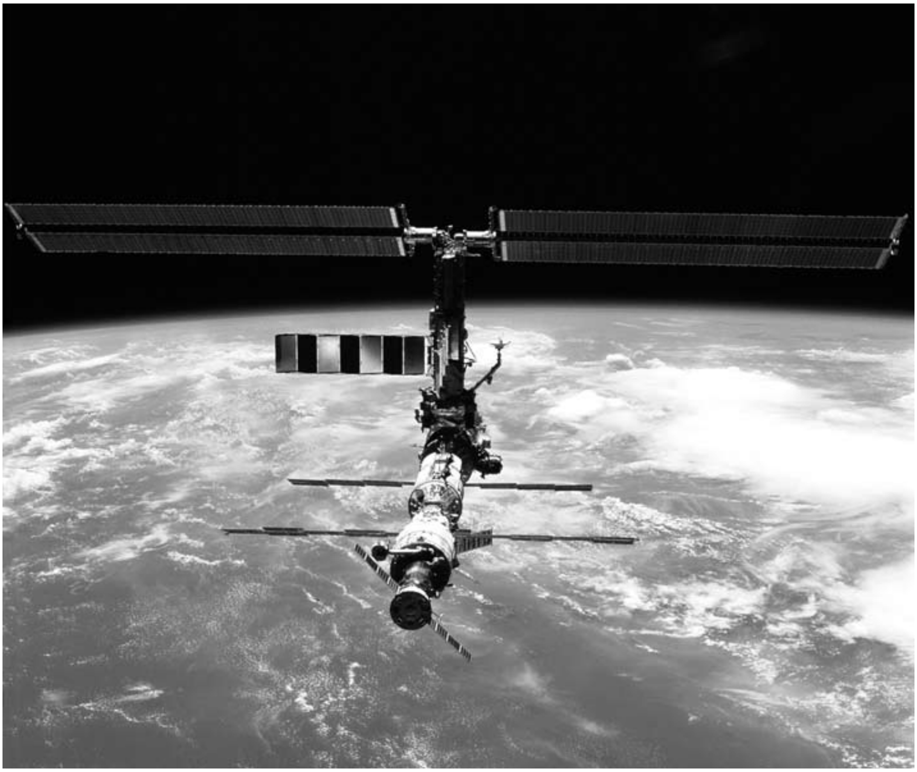
Flight rules now require continuous, live, high-resolution video of the External Tank during the Shuttle's ascent into orbit. To this end, Enhanced Launch Vehicle Imaging System, or ELVIS, cameras are mounted on the Orbiter, SRB and the tank itself. The goal is to provide the ground with engineering and visual data to assess the vehicle condition and tracking of debris during launch and ascent. To meet this flight-critical ("Crit 1") safety requirement, the integrated network stations of Merritt Island/Ponce de Leon, Wallops Island and the Jonathan Dickinson Annex provide the necessary and seamless link needed for ELVIS to work.[9]

With respect to communications with the ISS, several upgrades have been implemented in recent years or will be in the near future. One such modification goes by the catchy acronym of IDEA: ISS Downlink Enhancement Architecture. IDEA is in essence a modified ground system infrastructure that provides the space station with the ability to increase its science data return rate three-fold, from 50 megabits-per-second to 150 over the station's Ku-band downlink. A fiber optic ground network began in 2004 enabling JSC and MSFC to receive this high-rate data. It became operational in 2005.[10]

For TDRSS and the SN, GSFC and JSC have been working with the ESA since 1998 to make the system compatible and ready to support the latter's much anticipated Automated Transfer Vehicle, or ATV. ESA's ATV will be an automated, resupply ship designed to dock to the ISS and provide the crew with dry cargo, oxygen, water, and propellant. After cargo is unloaded, it will be reloaded with waste products, undocked, and set on a course for destructive reentry.

The first craft—to be named Jules Verne after the nineteenth century French science fiction writer—is considered by ESA as the most sophisticated space vehicle ever to be built in Europe. To support these partner objectives, Goddard completed a series of communications compatibility tests in Bremen, Germany in 2004.[11] Parallel with this effort, NASA SN engineers are working with the Japanese Space Agency NASDA to develop a tracking and communication solution for their H-II Transfer Vehicle (HTV), the Japanese version of Europe's ATV. Coding, data rate, and modulation upgrades to the TDRSS are anticipated to be complete no later than 2007.[12]

Finally, there is the familiar matter of television. What started humbly on Apollo 7 has come full circle, with HDTV. Just like consumer demands for better and better pictures from sporting events to big-screen IMAX pictures, images from space are no different. Starting with STS-114 (the first flight after the *Columbia* disaster), real-time HDTV was downlinked. Future HDTV sponsors include the Japanese along with the American cable television's Discovery Channel. Using customer-furnished hardware, HDTV



Backdropped against water and clouds, the International Space Station (ISS) was photographed by the crew of STS-102 on 1 March 2001 as they headed home in the Space Shuttle *Discovery*. In the foreground is a Russian Soyuz still docked to the station. Major construction of the ISS is scheduled for completion in 2010, at which time, NASA will transition American human space transportation from the Space Shuttle to the Crew Exploration Vehicle. (NASA Image Number MSFC-0102549)

signals will be downlinked from the ISS via TDRSS and distributed to users at the NASA Field Centers and to domestic and foreign customers.

The trend is clear. Space communications will remain an international activity, just like it was when it all started back in the 1950s. As it did then, NASA Headquarters will play a leading role to establish partnerships with the international space community. In the late 1980s, the Space Networks Interoperability Panel (SNIP) was informally created at an international conference under the direction of then Associate Administrator Robert Aller. At that time, differing space data relay systems were in various stages of planning and development by NASA, ESA, and NASDA. It was the first forum specifically designed to discuss, anticipate and try to resolve differences in the design and operation of the different systems with their stakeholders. The routine meetings among the agencies identified, for example, frequency differences, on-orbit locations, user operation limitations, and even emergency backup support scenarios in the event of total space communication system failures.[13]

This panel was followed in the June of 1999 by the formal establishment of the Interagency Operations Advisory Group, or IOAG. Here, top officials from NASA, Italy's Agenzia Spatiale Italiana (ASI), the French Centre National D'Etudes Spatiales (CNES), Germany's Deutsches Zentrum für Luftund Raumfahrt (DLR), the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA), meet annually (at rotating host countries) to coordinate space communications policies, procedures, technical interfaces, and many other matters related to interoperability. The group itself does not do—for the most part—the technical work. It relies primarily on technical work already completed by other organizations, for example, that develop standards for space systems. However, when a deficiency or inconsistency is discovered, the IOAG may recommend to such organizations that they address the missing areas in their work. By doing so, a common framework is laid that enables synergy and cooperative efforts among all the international partners.[14]

In the same vein, in 1995 and 1996, NASA was an active participant in the National Facilities Study—a joint effort by the DOD, NOAA, NASA, and other U.S. government participants—the basic premise of which was to reduce duplication and identify areas of national need. One of the sub-panels was devoted to aerospace tracking and communications capabilities. It was in this panel that issues regarding frequency usage, allocation, and station locations were addressed. There was also extensive discussion regarding synergies between NASA and NOAA in places like Alaska for mutual cost savings and improved coverage. Like the IOAG and its predecessor the SNIP, the National Facilities Study addressed and tried to resolve the spectrum differences and expedite cooperative operations amongst the agencies.[15]

With respect to ground station operations, since Earth is round and the United States obviously does not own territory everywhere, it has been and always will be an international activity. In other words, if NASA has a requirement on foreign soil, it has no choice but to go to the other country. This actually has inherent advantages. Said Bill Watson:

> I think the really neat thing about the early ground network was that many of these countries welcomed us in because they wanted to join the space program. But they also welcomed us in on the condition that we train their people, hire them to become technically literate and competent. We did a lot of that. We had a NTTF at Greenbelt that ran classes for years and put thousands

> of people through and trained them up in receivers and recorders and computers and how to solder and all kinds of techniques. They then took that back home and became technically competent in the countries that they came from. I think we still see that desire to engage, even with our peers today.[16]

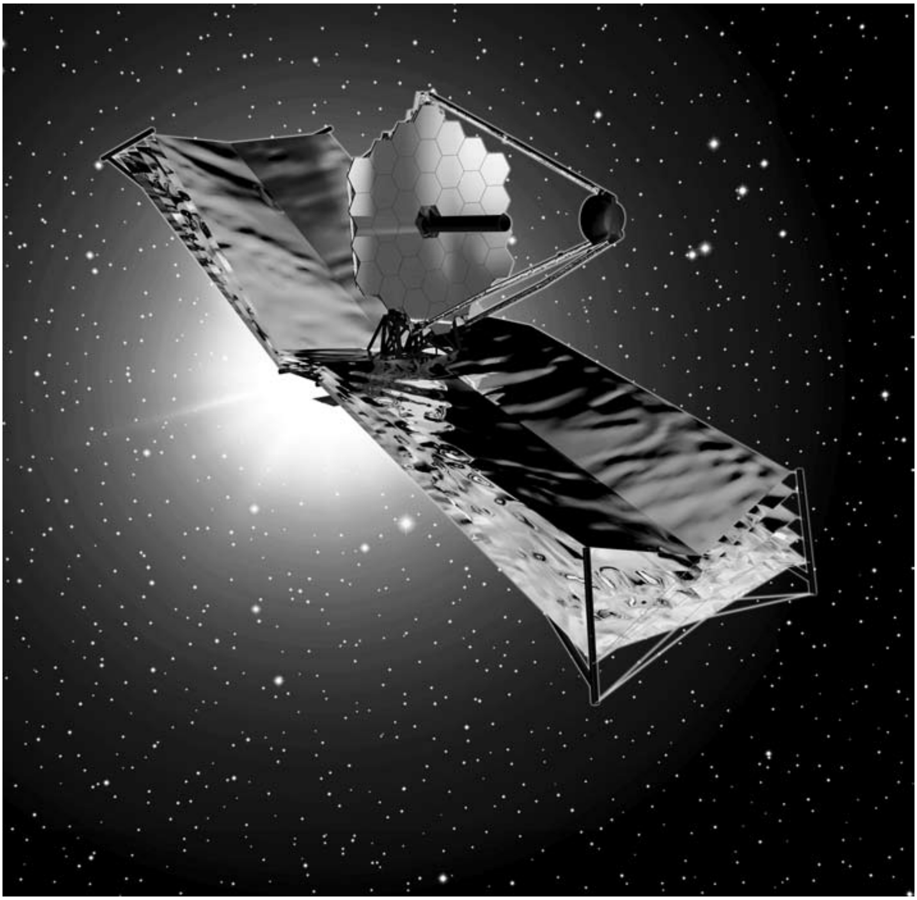
While Earth science will always be there serving to anchor near-Earth space activities, the future for NASA—as it was in the past—is exploration. Here, synergies exist between science and sending astronauts back to the Moon and onto Mars, neither of which can be done without defining the space communication requirements. NASA Headquarters has set up, for this purpose, a Communication and Navigation Architecture Working Group to define and lay the foundation for its communication and navigation infrastructure for the next 25 years. One concept is a plan for an Integrated Near-Earth Network (INEN).

Although only a proposal, the elegance of an INEN is attractive since it would involve building a network one mission at a time. One of the first ingredients is Goddard's Solar Dynamics Observatory (SDO), a geosynchronous mission that will monitor solar storms and send back information which will be a benefit to astronauts in space in case of storms. It will do this, plus provide warnings of commercial communications disruptions here on Earth.

In conjunction with development of the SDO is the LRO, or Lunar Reconnaissance Orbiter. To support these projects, NASA's next expansion in ground stations may again be at White Sands, New Mexico where three 60-foot Ka-band antennas could be built to support these missions. Both the SDO and LRO will utilize the Ka-band frequency for communications where ever higher bandwidths and data rates can be accommodated. (Today most of NASA's communications are at X-band which is fine for data rates of around 150 megabits-per-second.) With the advancement to Ka-band, though, data rates can be increased by over a factor of three, to 500 megabits-per-second.[17]

With Ka-band capability, the kernel—or seeds—for an exploration network at White Sands could be established. The idea is that once SDO and LRO are over, this resource could then become part of a Ka-band network for lunar exploration. As the need arises, S-band commercial sites—for instance, in Australia and South Africa—can be used to supplement White Sands. As it does today, NASA can buy these lower rate services commercially. As the Exploration Program matures and as the need for high rate data requirements expands, the Agency might then consider putting additional Ka-band dishes in places like South Africa, Australia, or Madrid to complete its mid-latitude, high data rate network for exploration.[18]

The idea is that although the DSN has traditionally been responsible for planetary communications, it will help support near-Earth work as



Pictured is the chosen artist's rendering of NASA's next generation space telescope. A successor to the Hubble Space Telescope (HST), the futuristic James Webb Space Telescope (JWST) is named in honor of NASA's second administrator, James E. Webb. To further our understanding of the way our universe formed, NASA is developing the JWST to observe the first stars and galaxies in the universe. The new telescope will carry a near-infrared camera, a multi-object spectrometer and a mid-infrared camera-spectrometer. The JWST is scheduled for launch in 2010 aboard an expendable launch vehicle. It will take the spacecraft three months to reach its destination, an orbit of 1,513,000 kilometers (940,000 miles) in space. The Marshall Space Flight Center (MSFC) is supporting Goddard in developing the JWST by creating an ultra-lightweight mirror for the telescope at Marshall's Space Optics Manufacturing Technology Center. The program has a number of industry, academic, and government partners, as well as participation from the European Space Agency and the Canadian Space Agency. (NASA Image Number MSFC-0202886) well since GSFC has closed down its large tracking antennas in places like Rosman and Fairbanks. Since the TDRSS coverage zone stops at around 12,000 kilometers (7,400 miles)—the point at which TDRSS can no longer provide continuous communications with a spacecraft—new 18-meter (60-foot) Ka-band systems will be added to cover the gap between near-Earth and deep space. It in effect pushes the boundary of the NEN out to somewhere around two million kilometers (1,240,000 miles), which is where near-Earth transitions to deep space from a spaceflight point of view.[19]

Of particular interest in recent years are spacecraft that can be located at five distinct points in space where the gravitational pull of Earth, Sun, and Moon all balance out. A craft positioned at one of these "Lagrange Points" (named after Italian-French mathematician Joseph Louis Lagrange) can "hover" there in a so-called lissajou orbit—somewhat akin to the "figure-8" loop that a geosynchronous satellite does over Earth except the orbit would not be stable. One point in particular, called "L2," is approximately 1.5 million kilometers (932,000 miles) away from Earth beyond the Moon. In the coming decade, NASA plans to put several astronomical observatories there, including the much anticipated James Webb Space Telescope—the follow up to the HST. Space will be a busy place.[20]

Under the envisioned Integrated Near-Earth Network, the Agency could use a combination of 18-meter Ka-band antennas plus the TDRSS to provide seamless coverage on a space mission. Take a Mars exploration mission for instance. As it is launched out of the KSC, it would be supported from a Merritt Island/Ponce de Leon-like station, but equipped with Ka-band. Just like the Shuttle, it would then transition to TDRSS soon after launch. But as the vehicle leaves Earth's orbit and out of TDRSS coverage, the new Ka-band antennas at mid-latitude locations such as New Mexico, South Africa, or Madrid and Australia would pick up its signals much like the Apollo stations did with their Unified S-Band antennas in the 1960s and 1970s. Finally, as it goes beyond two million kilometers towards Mars, coverage will transition over to the DSN.[21]

NASA's tracking and data network will have then come full-circle, albeit this time with much faster data rates, much higher bandwidths and much more autonomy than before. This is really but a reflection of the cyclical nature of space exploration. The first satellites went into orbit to explore Earth. This was followed by space probes to the Moon and the planets. After America sent 12 astronauts to the Moon and won the space race, the Agency once again concentrated on Earth science, both un-crewed and with human presence (the ISS). In the coming decades, this cycle will likely shift once again to emphasize human exploration, not only of the Moon but this time out to Mars and beyond.

To this end, NASA's Exploration Systems Mission Directorate plans to start flying the Crew Exploration Vehicle soon after the three Space Shuttle

Orbiters are retired in 2010. To ensure continuity, the TDRSS will have to deploy new satellites in the 2012 to 2015 time frame. As astronauts return to the Moon, the Agency will likely need some type of lunar relay system to be able to communicate with the spacecraft when it is on the back side of the Moon. Much has happened in the three-decades since Apollo last went to the Moon. Tragedy, unfortunately, has played a major role. To enter lunar orbit, the Apollo Service Module had to fire its engine on the backside of the Moon out of communication with Mission Control. After *Challenger* and *Columbia*, the Agency will likely not want to fire another rocket without having a communication link and knowing what happened. Thus, there is expectation at NASA that a TDRSS-like system on the backside of the Moon may have to be built before returning astronauts there.

The challenges don't stop there. Farther down the road, as mankind places our first steps on Mars, high-definition television will have already been a fixture for many years. The world is going to want to see pictures *a lot* clearer than what it saw with Armstrong and Aldrin. To do this, an optimal array of antennas and frequencies will be needed. The magnitude of the challenge should not be understated. For example, architectural studies have shown that in order to receive 100-megabits of low bit-error data from Mars, 100 to 300 12-meter (40-foot) antennas will need to be arrayed together in one location![22] Not impossible but clearly a challenge. Then there is the issue of relay and perhaps more importantly, delay. It takes light and radio signals anywhere from 3 to 18 minutes to reach Earth from Mars—the exact time depending on where the two planets are with respect to each other. One might ask, does the information we receive have to be real-time or is it good enough to just have the information tell what happened?

Delay-tolerant networking is even today a major issue for NASA (and for information technology at large). A simple example would be the case of a person using wireless internet access on a bus or a train. As he travels through a tunnel and loses his session, he would not want to have to start all over again when he resumes the session on the other end. The issue is how to get internet standards to evolve to the point where they can reliably cope with delays.

NASA will be busy.

With President Bush recommitting America to human space exploration, the National Aeronautics and Space Administration has been offered an opportunity that was not really all that well formed prior to 2004. With that vision comes the opportunity for NASA to take a new look at where it is going as the nation's space agency, and in particular, where it is going from a space communications point of view. The two are inextricably tied together. In sort of a twist on the popular American Express advertising slogan, those who work the networks at the Agency have adopted as their unofficial tagline "Space Communications: Don't Leave Earth Without It" when describing the indispensable role that the tracking and communications networks have played over the years.[23]

Because space communications are not easy, those who build the network are really building an enabling capability for the future. Just as the MSFN enabled the United States to safely go to the Moon and back, today the TDRSS enables the ISS and other data-rich spacecraft to return the amount of data that they were designed for. In many ways, as the previous generation did for today, those who now work the Space and Ground Networks are setting up for what is to come for the next generation.

The story of America's global spaceflight tracking network is ultimately the story of the men and women who made space communications a reality before it became the neat thing that it is today, something that we cannot live without. When Apollo 11 landed on the Moon in 1969, 56-kilobit connections to ground stations were a big deal. Today, the space agency hauls 4.5-*terabytes* (that is, 4.5-trillion bytes of digital data) a day back to Earth at an average rate of 100-megabits (100,000,000) per second.[24]

As one walks the hallways of NASA, whether it be the GSFC, the JSC or Headquarters, there are televisions all around showing videos of astronauts working in the ISS, spectacular images of celestial bodies from across the galaxy taken by the Hubble Space Telescope, or live pictures of storm patterns developing on the other side of the planet. As Bob Spearing, NASA's former top official for space communications, put it:

> None of that—*none of it*—would be there without space communications. So when I walk by and somebody is looking at the television screen, I ask 'Do you know how that picture got here?' Most of them say no. Most people don't have any idea. I'll then go through a little talk about how the picture got here—and there is a real appreciation then. From a legacy point of view, there are a couple of things. One thing is that communications is ubiquitous and it is a capability that we all assume and just move on. We don't give it a second thought until it doesn't happen. If you look back over time, I believe you'll be hard pressed to find a mission that was compromised in any way by lack of communications. So our legacy is we deliver the goods and we always have. Every mission requires it and we have always delivered. . . . We made it work![25]

As the NASA enters the second half of its first century, a new generation of space probes and human explorers will lead the way back to the Moon, eventually venturing to Mars and beyond. As they make these journeys, men and women here on Earth will track them across that vast ocean of space.

After all, someone will have to stock the ships for the new Columbus and the new Magellan!